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**Zuniga et al.**

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(54) **CARRIER HEAD WITH A FLEXIBLE MEMBRANE FOR A CHEMICAL MECHANICAL POLISHING SYSTEM**

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( * ) Notice: Under 35 U.S.C. 154(b), the term of this patent shall be extended for 0 days.

(21) Appl. No.: **08/861,260**

(22) Filed: **May 21, 1997**

**Related U.S. Application Data**

(63) Continuation of application No. 08/745,679, filed on Nov. 8, 1996, now abandoned.

(51) **Int. Cl.**[7] ............................ **B24B 5/00**; B24B 29/00
(52) **U.S. Cl.** .......................... **451/285**; 451/287; 451/288
(58) **Field of Search** .................................. 451/285, 289, 451/287, 288, 286, 36, 41, 42, 290, 398, 256, 259, 247, 401, 332, 292, 397

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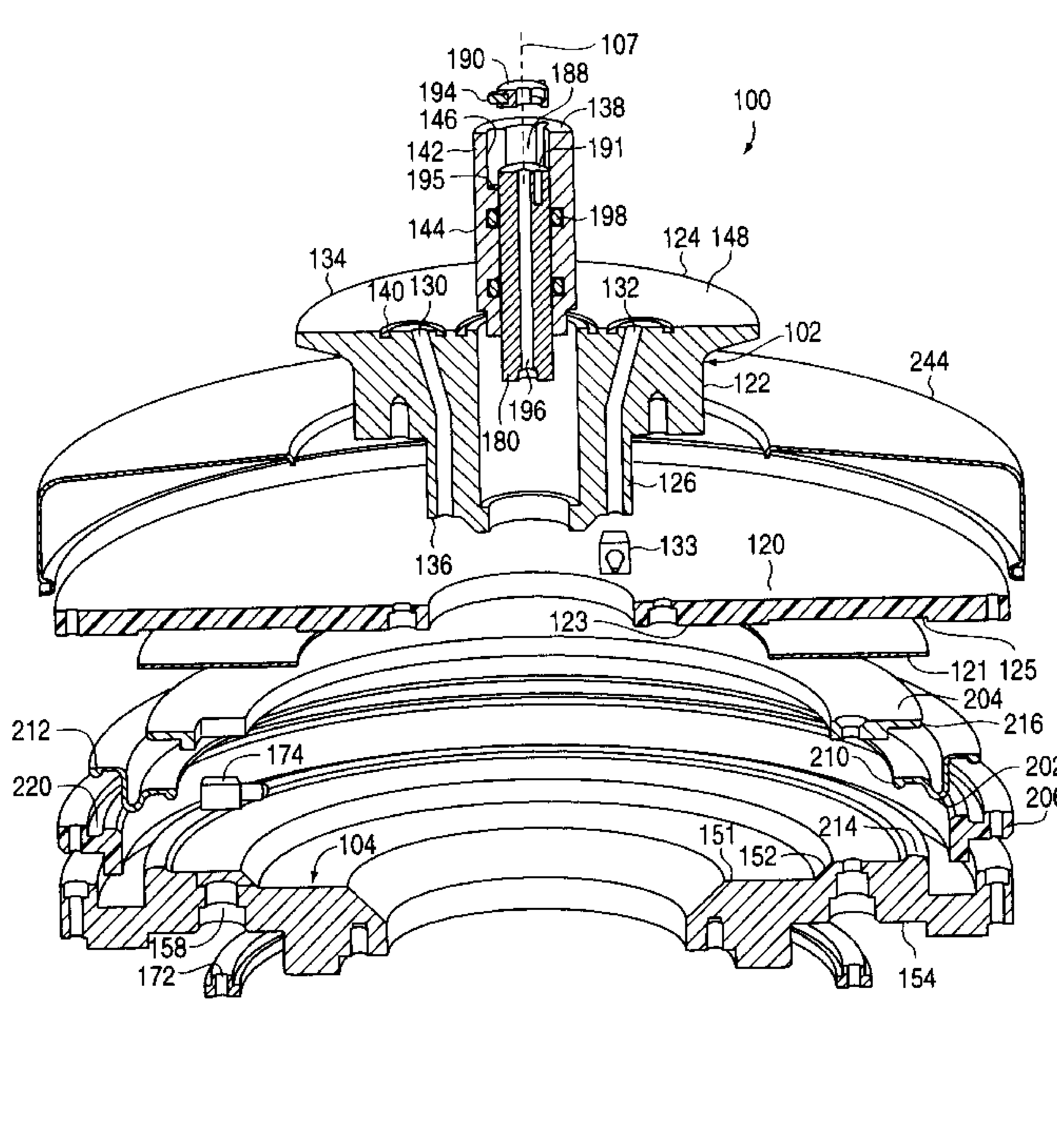
(57) **ABSTRACT**

A carrier head for a chemical mechanical polishing apparatus. The carrier head includes a housing, a base, a loading mechanism, a gimbal mechanism, and a substrate backing assembly. The substrate backing assembly includes a support structure positioned below the base, a substantially horizontal, annular flexure connecting the support structure to the base, and a flexible membrane connected to the support structure. The flexible membrane has a mounting surface for a substrate, and extends beneath the base to define a chamber.

**92 Claims, 20 Drawing Sheets**



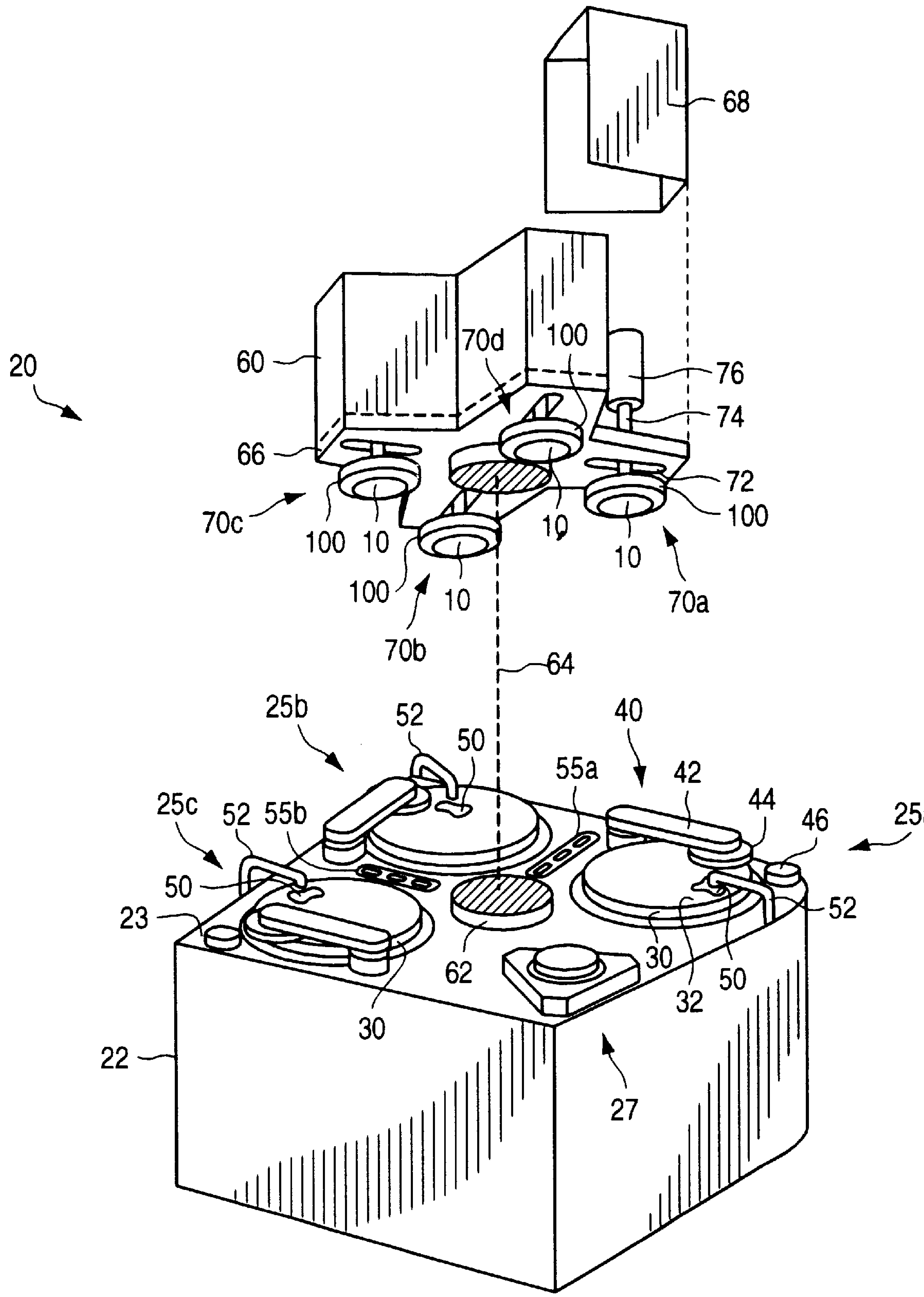

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FIG. 1

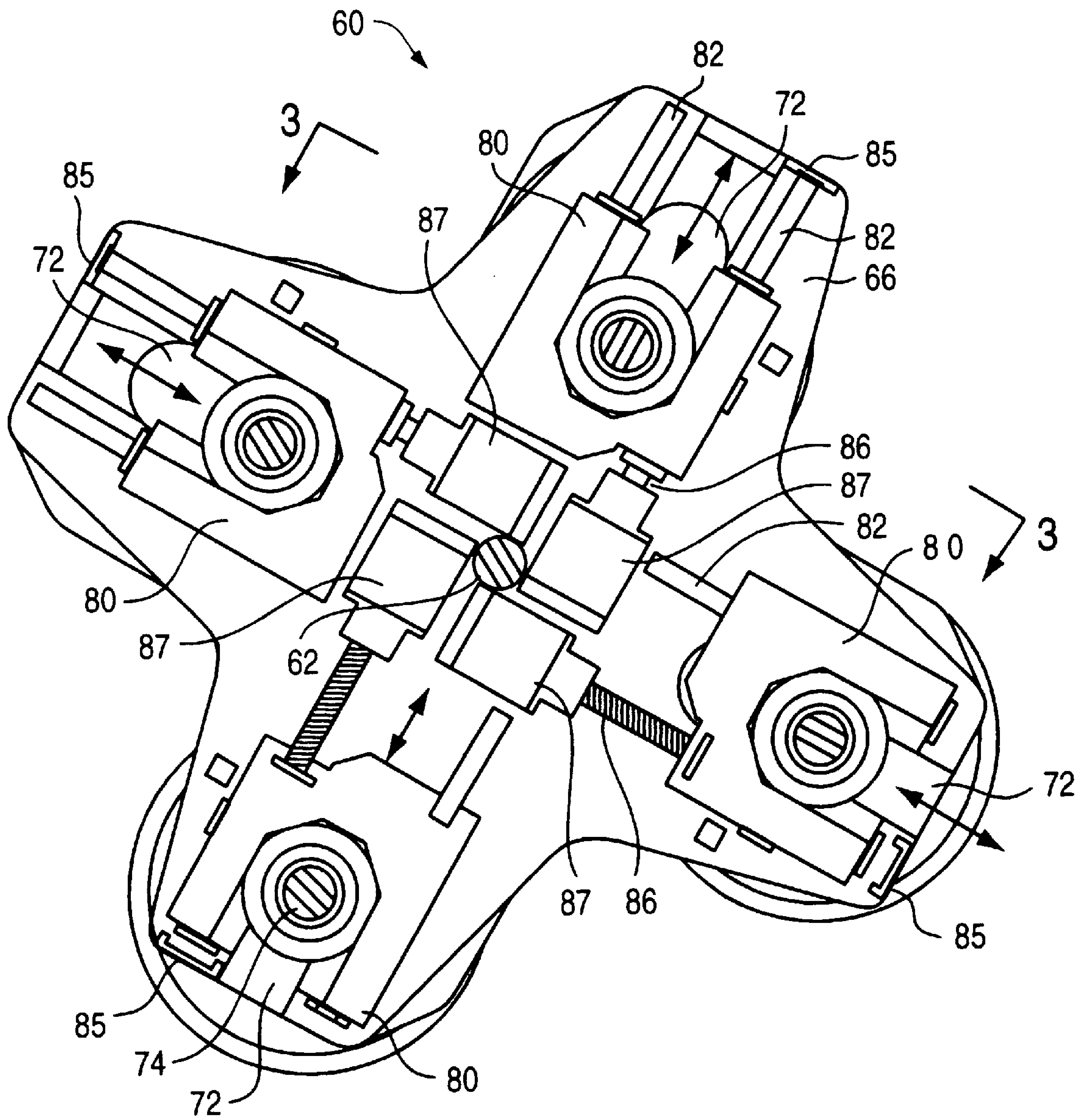
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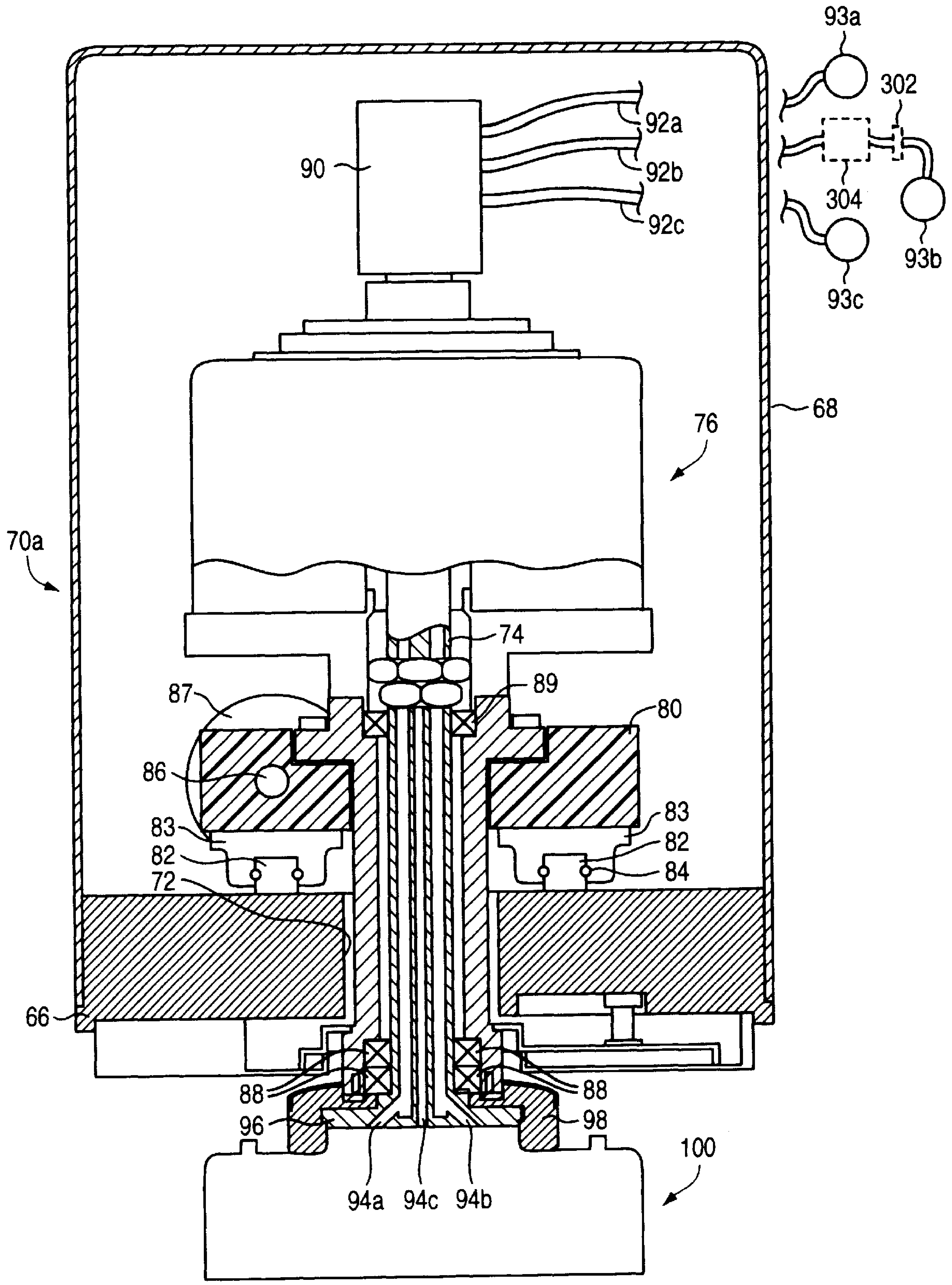
FIG. 2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94c
94b

FIG. 3

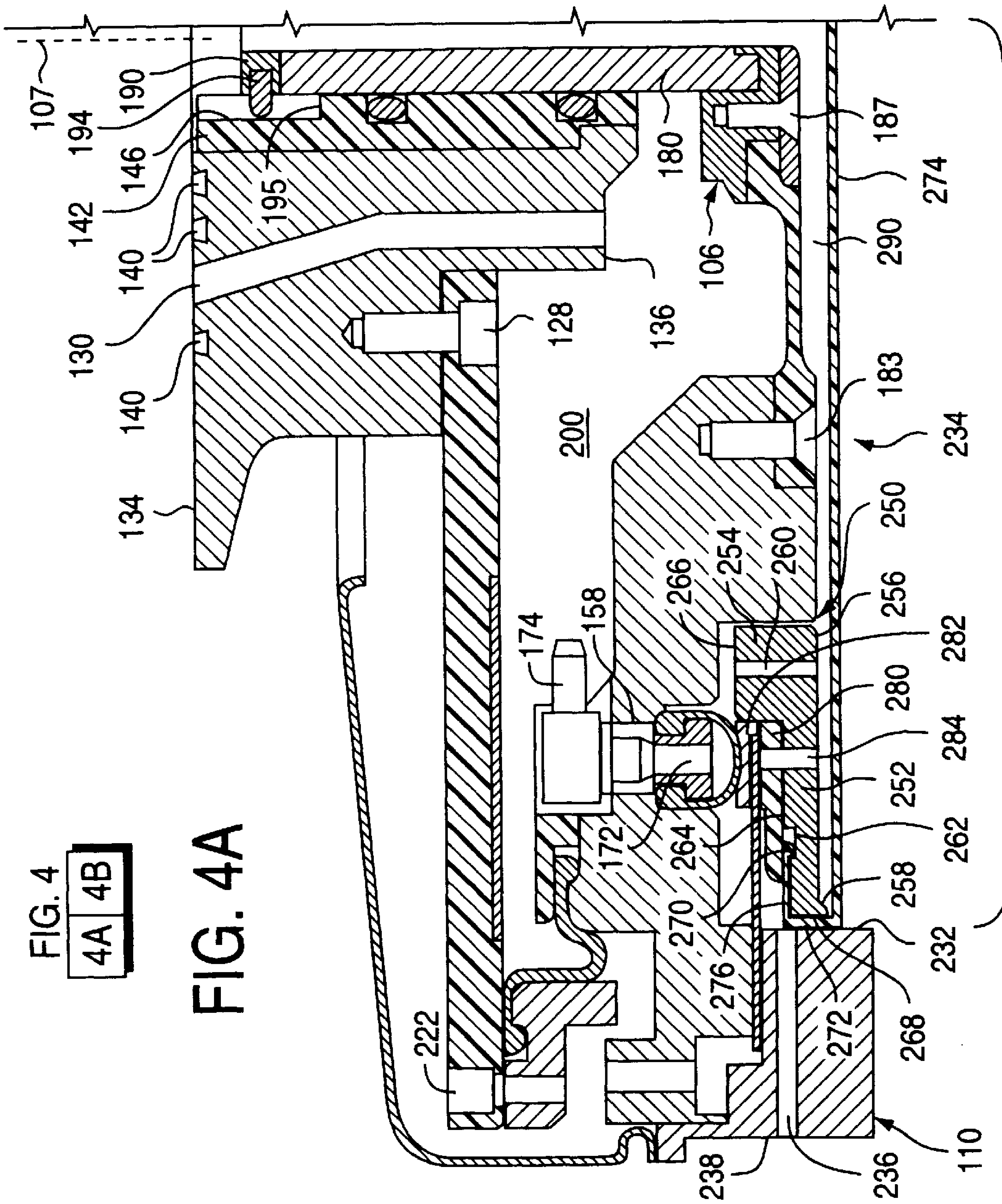
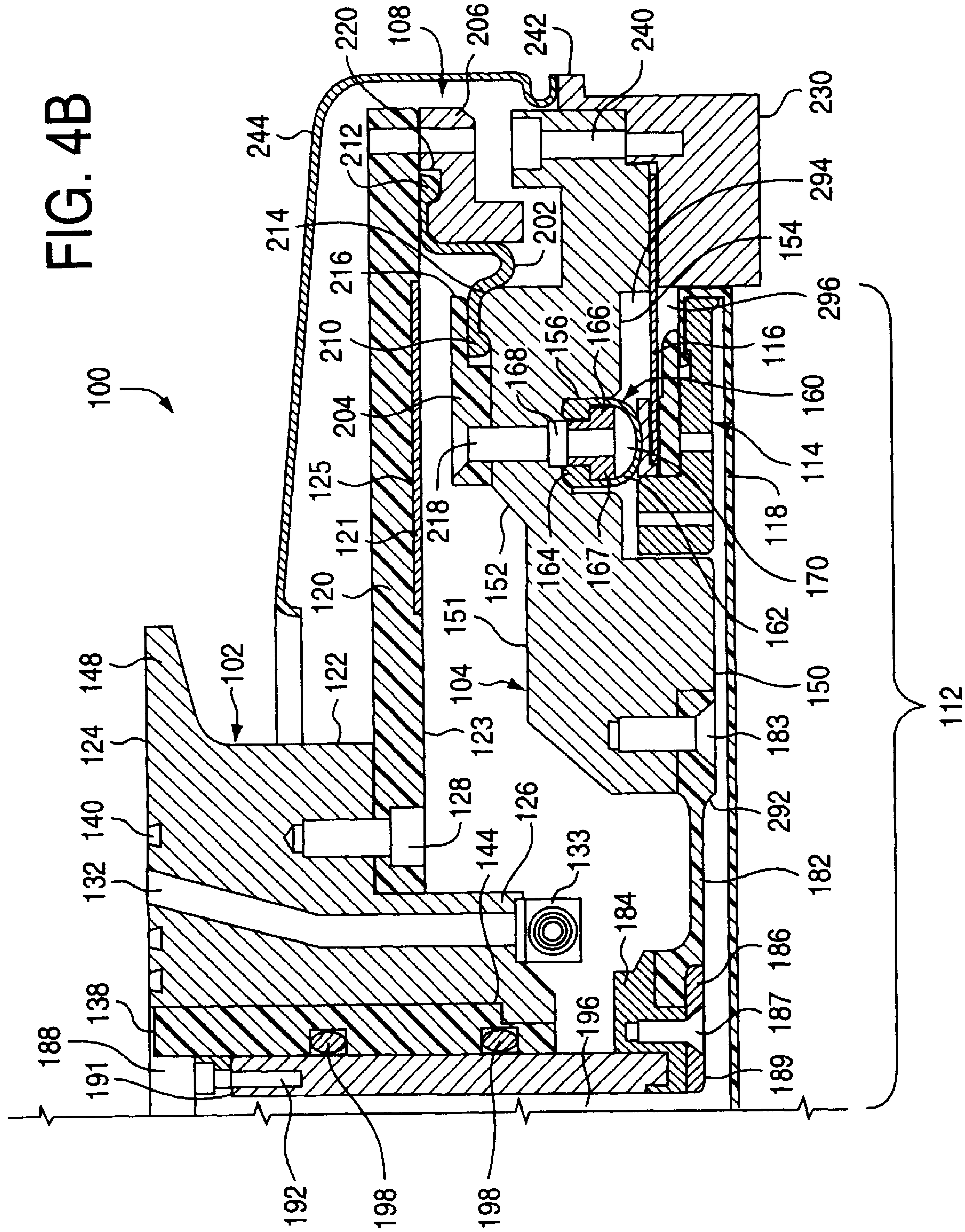



FIG. 4

4A 4B

FIG. 4A

FIG. 4B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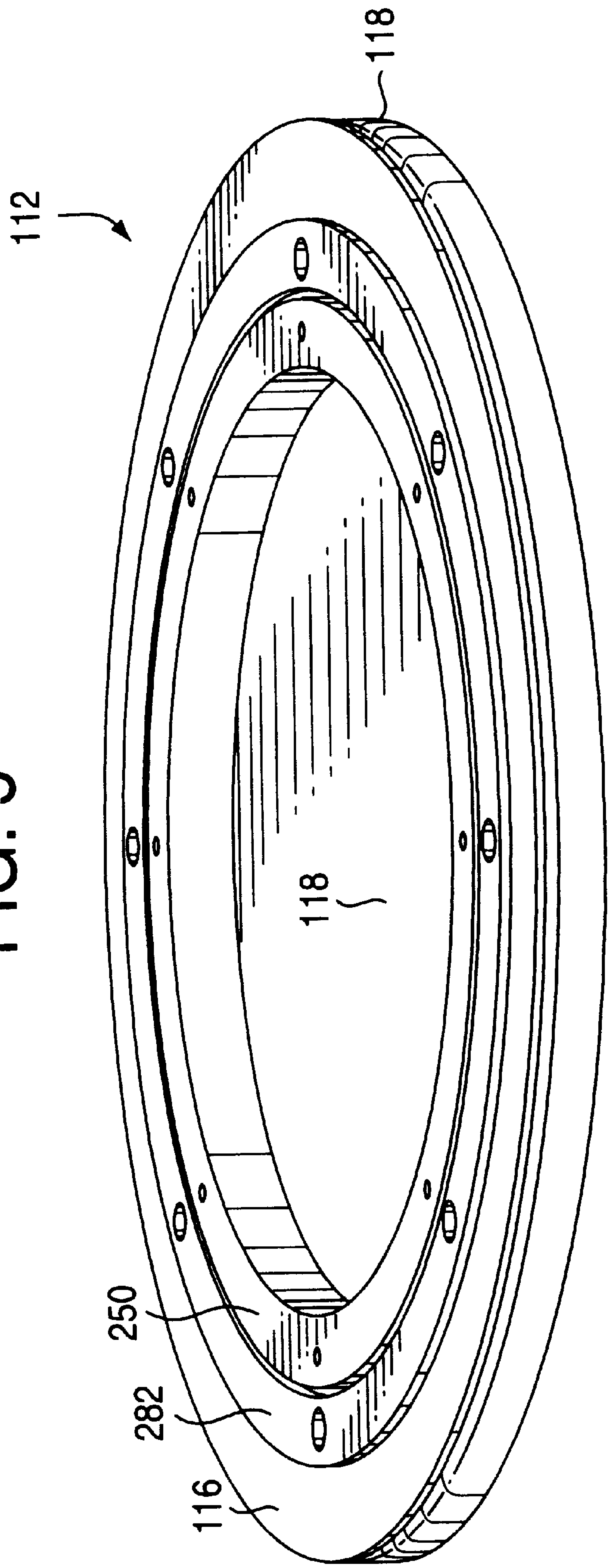



FIG. 5

FIG. 6A

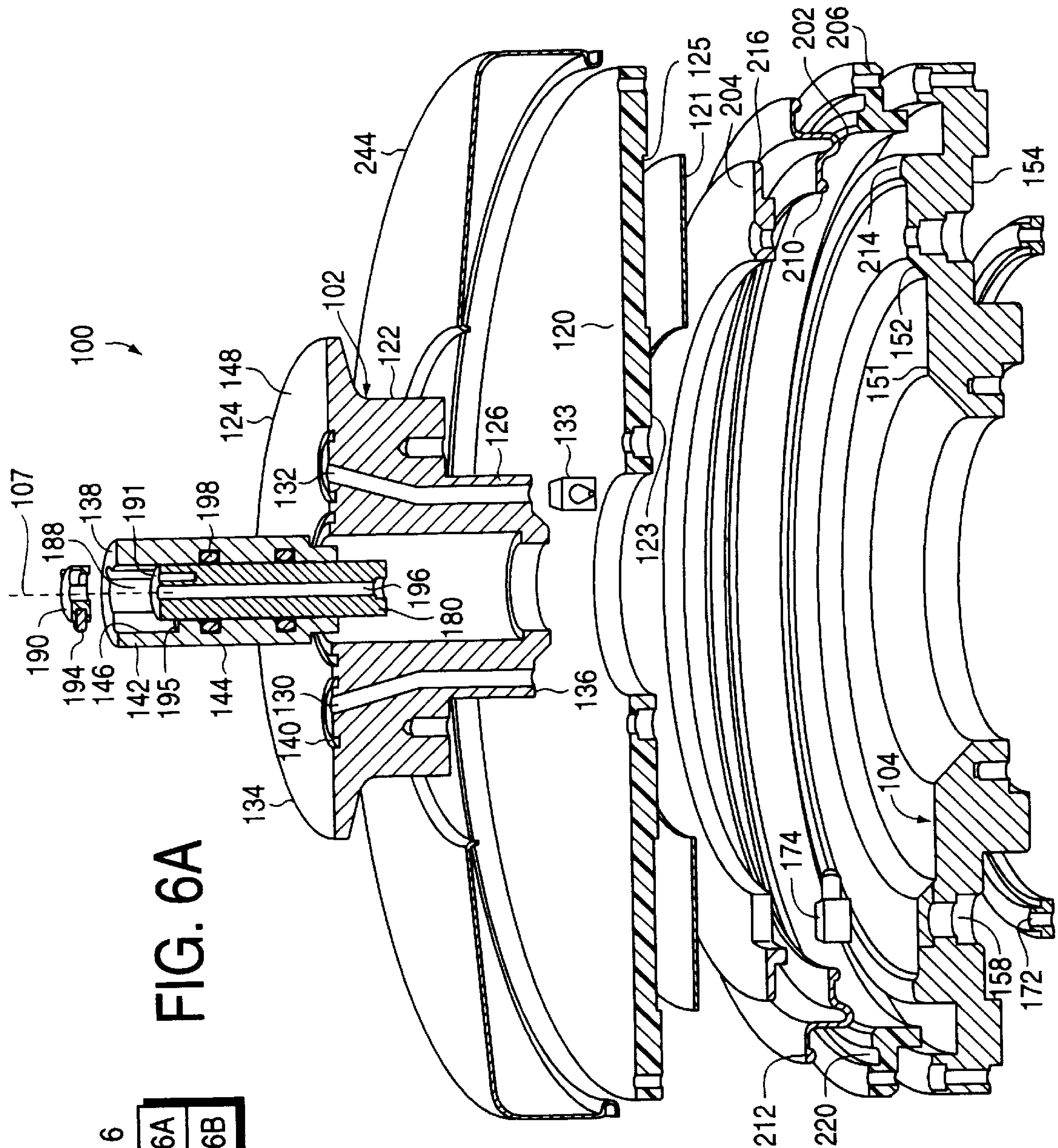
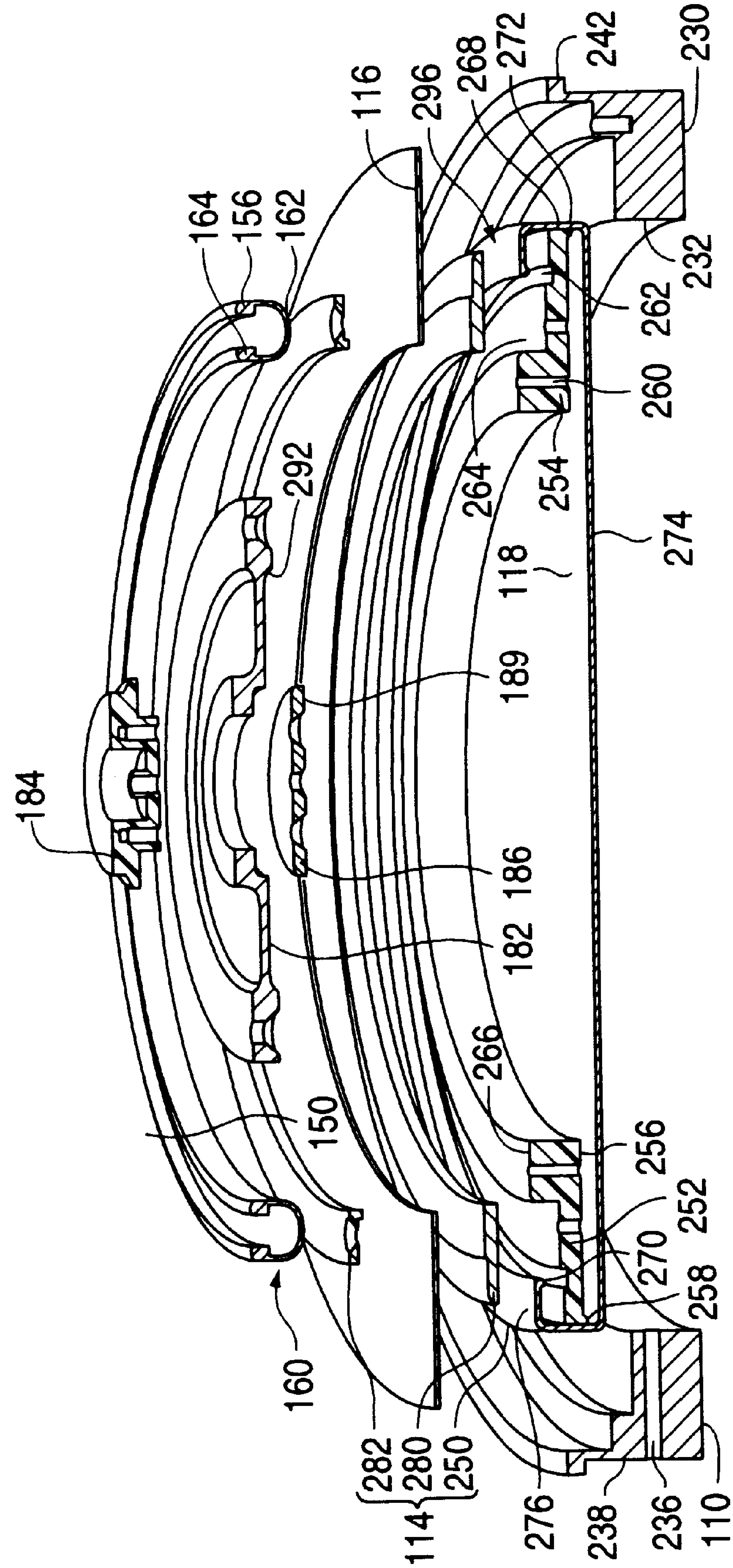



FIG. 6

| FIG. 6A |
|---|
| FIG. 6B |

FIG. 6B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266
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270
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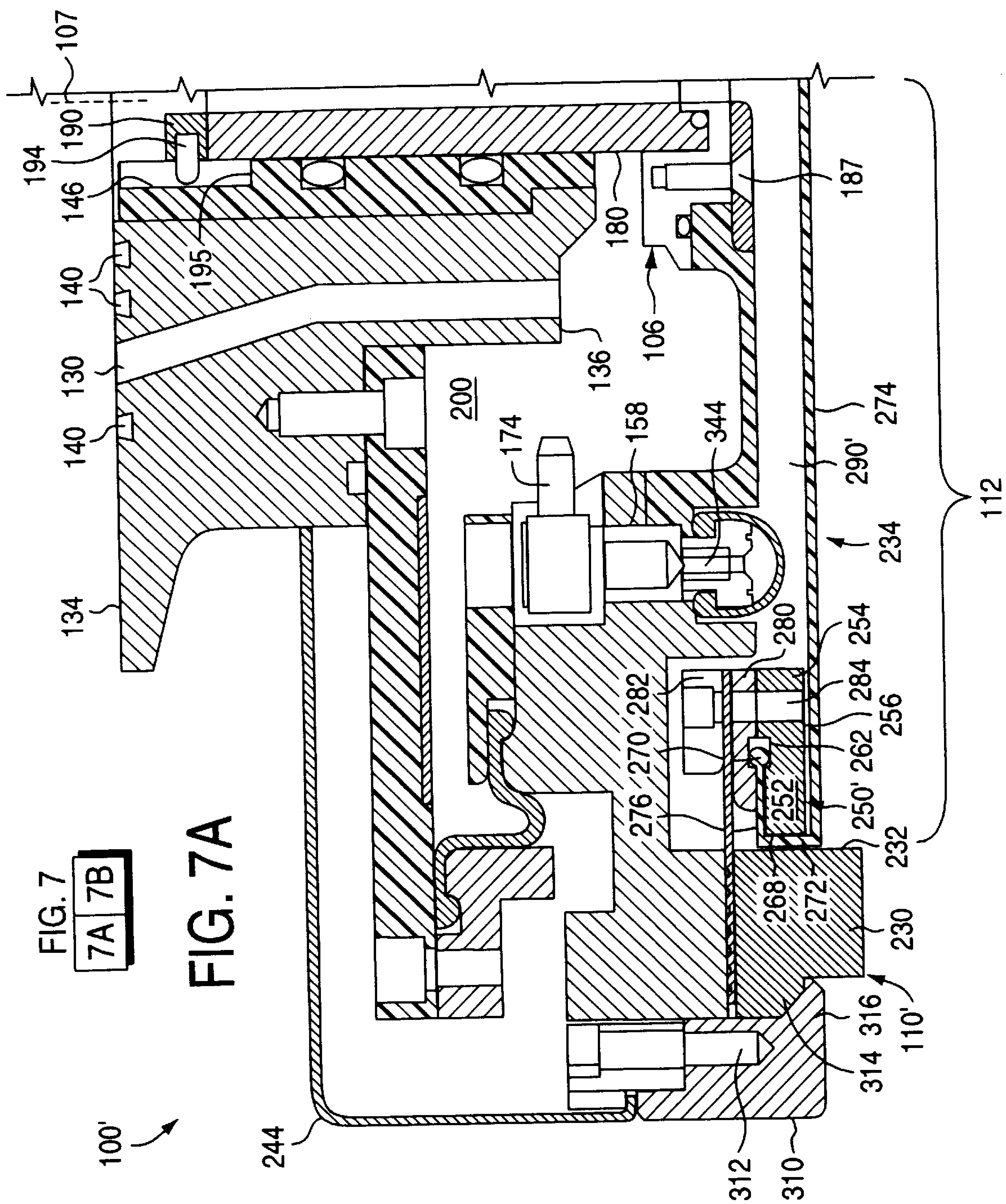
280
250
114
276
238
236
110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190
194
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195
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136
200
174
158
344
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234
112
280
254
282
284
256
270
262
276
252
250'
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268
272
230
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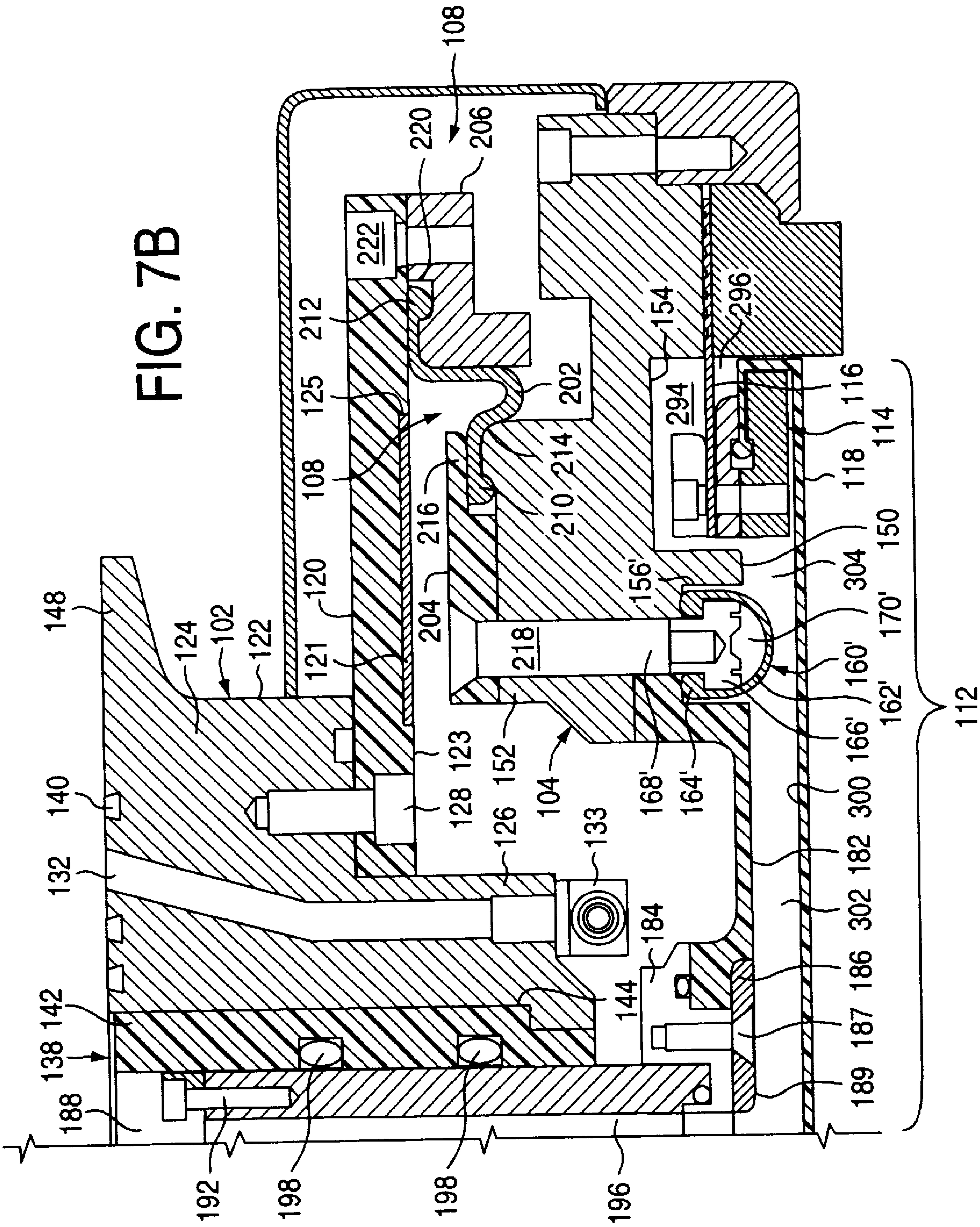
110'
314
312
310
244
100'
FIG. 7
7A
7B

FIG. 7A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124
102
122
121
218
170'
160'
162'
112
123
152
166'
168'
164'
300
140
128
104
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196

FIG. 7B

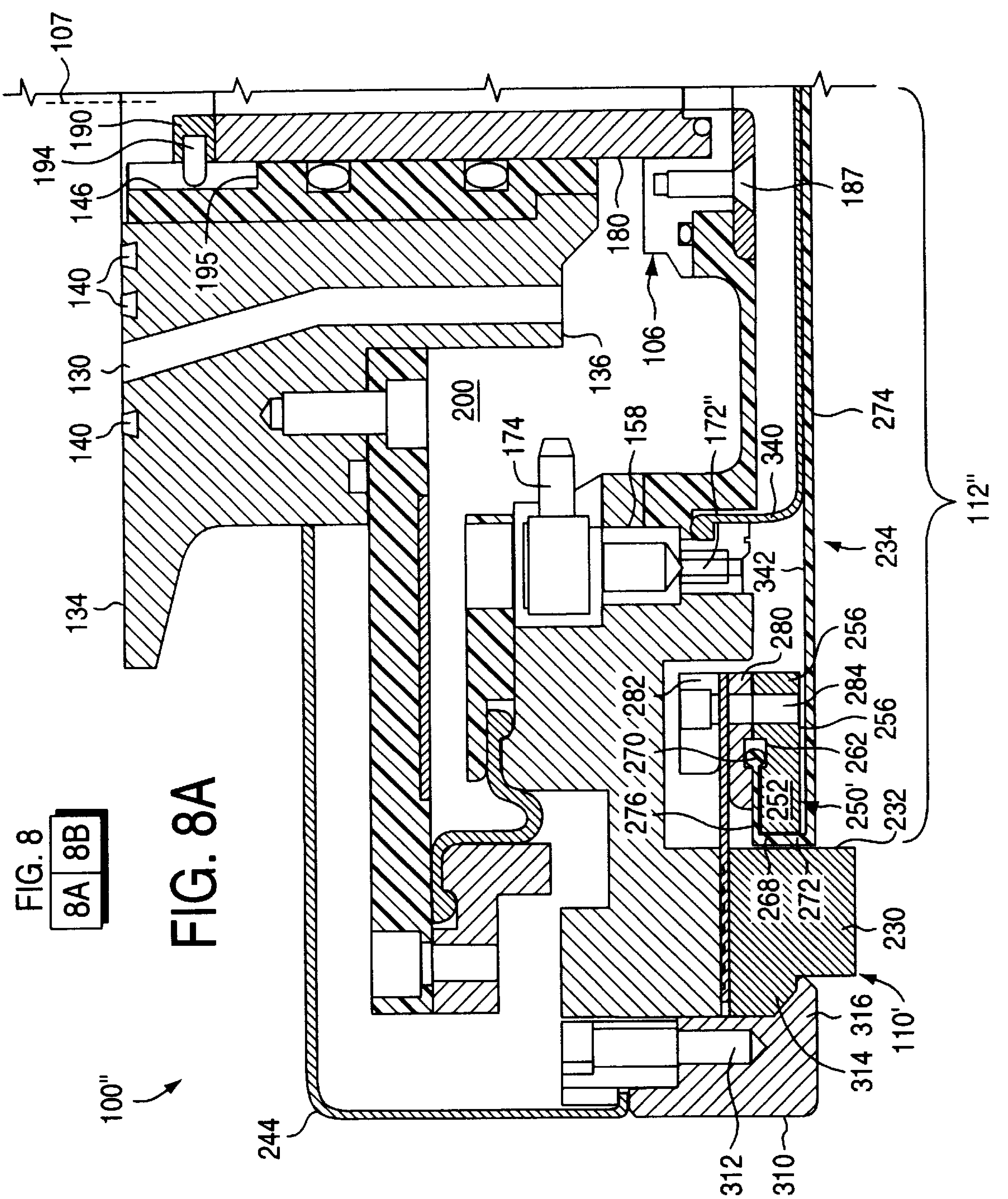
FIG. 8
8A
8B
107
190
194
146
195
140
130
140
134
136
200
174
158
172"
180
106
187
274
340
342
234
112"
280
256
282
284
270
256
262
276
252
250'
232
268
272
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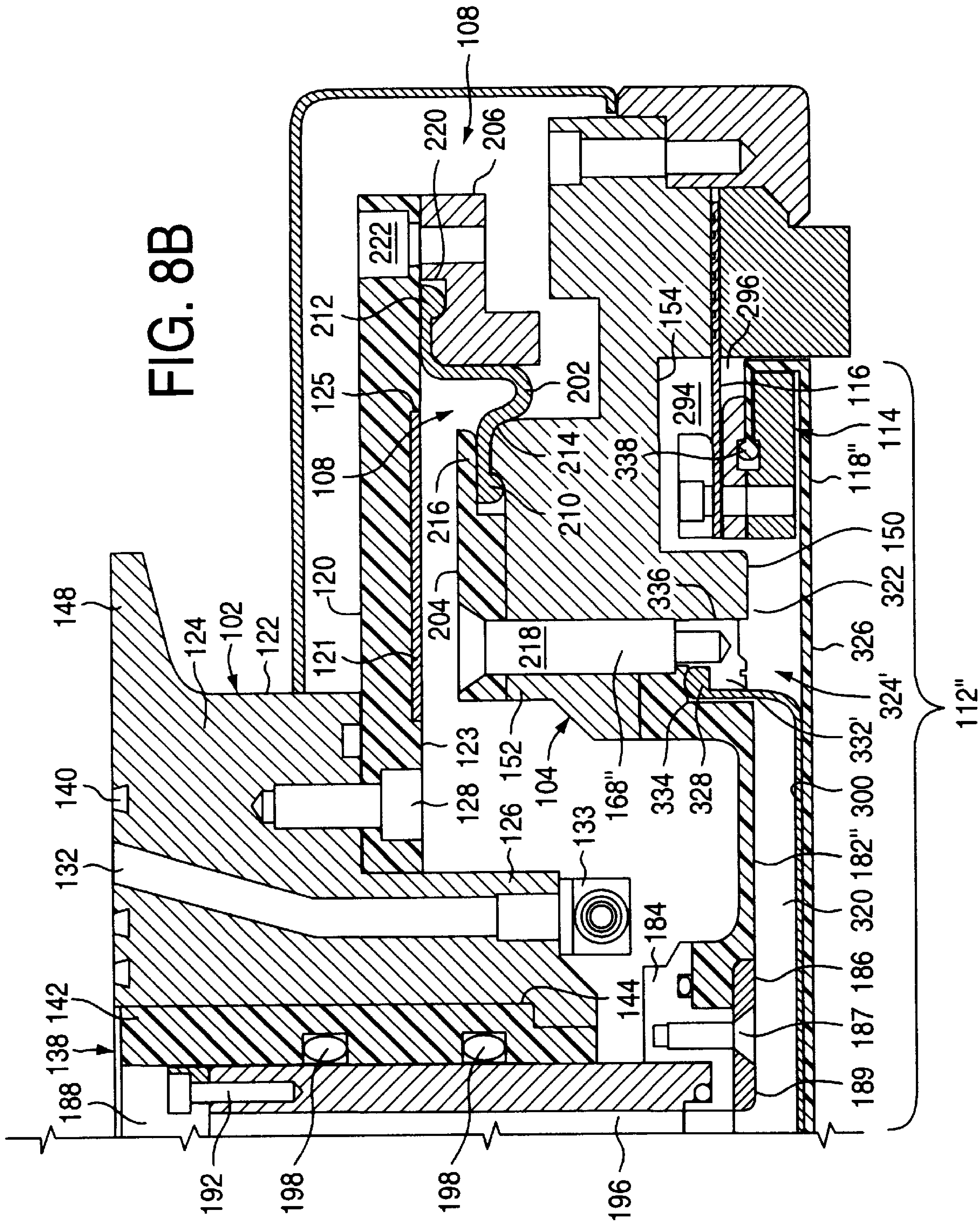
316
110'
314
312
310
244
100"

FIG. 8A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120
121
204
336
322
148
124
102
122
218
326
324'
123
152
104
168"
334
328
332'
300
112"
140
128
126
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182"
132
320
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186
142
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189
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198
198
196

FIG. 8B

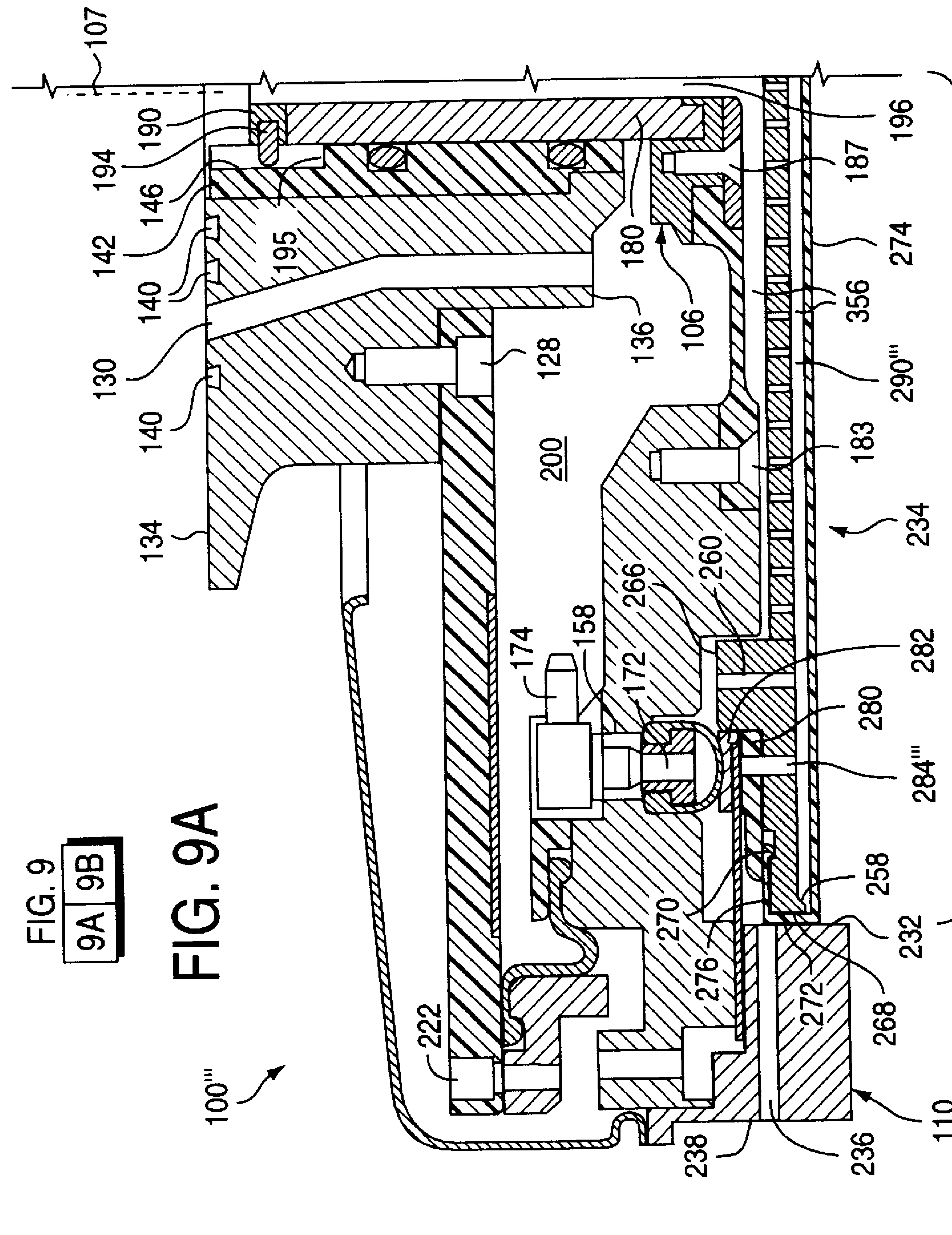
FIG. 9
9A
9B
107
190
194
146
142
140
140
130
140
134
195
128
136
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187
196
274
356
290'''
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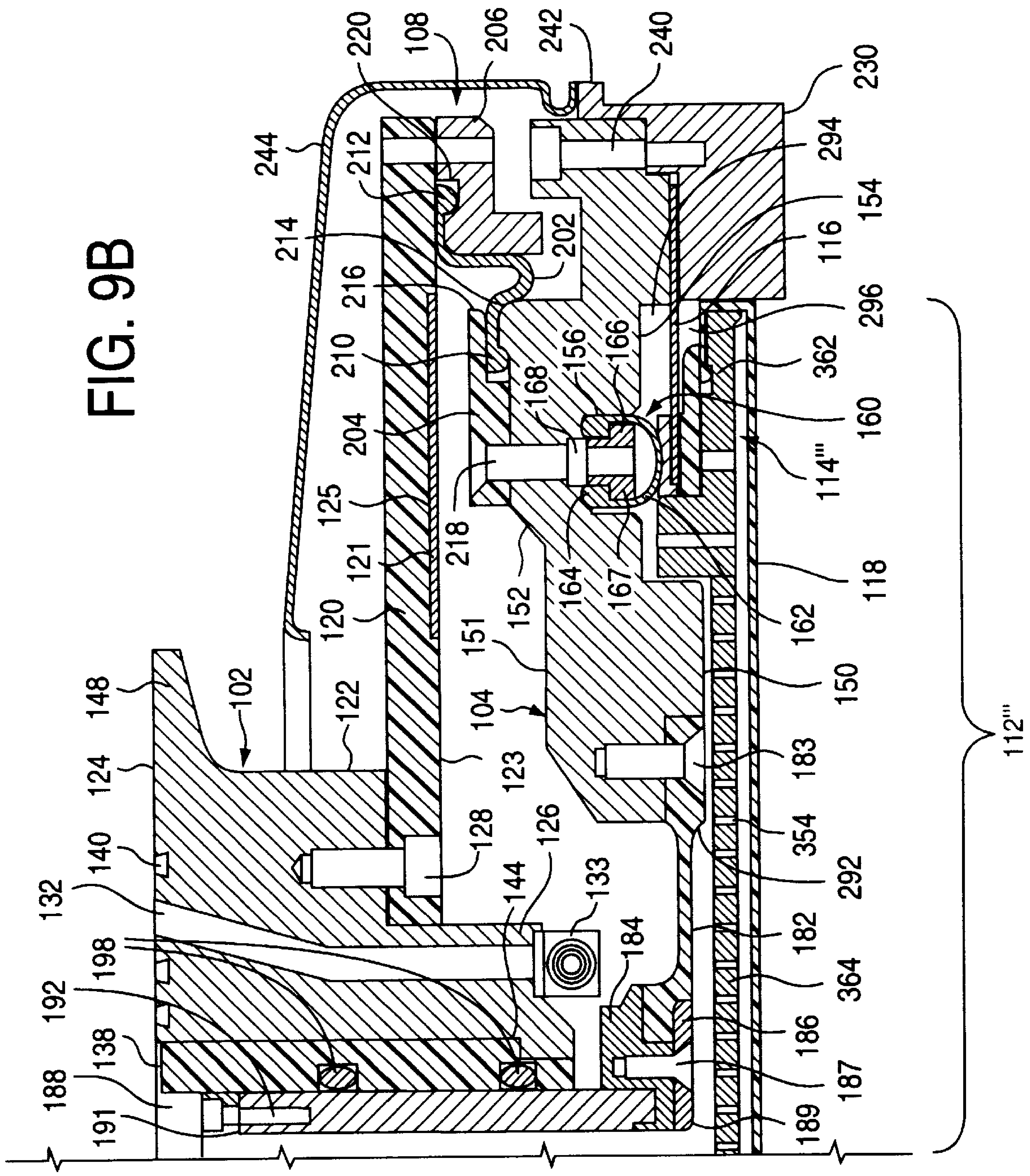
FIG. 9A

FIG. 9B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104
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364
138
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187
191
189
112'''

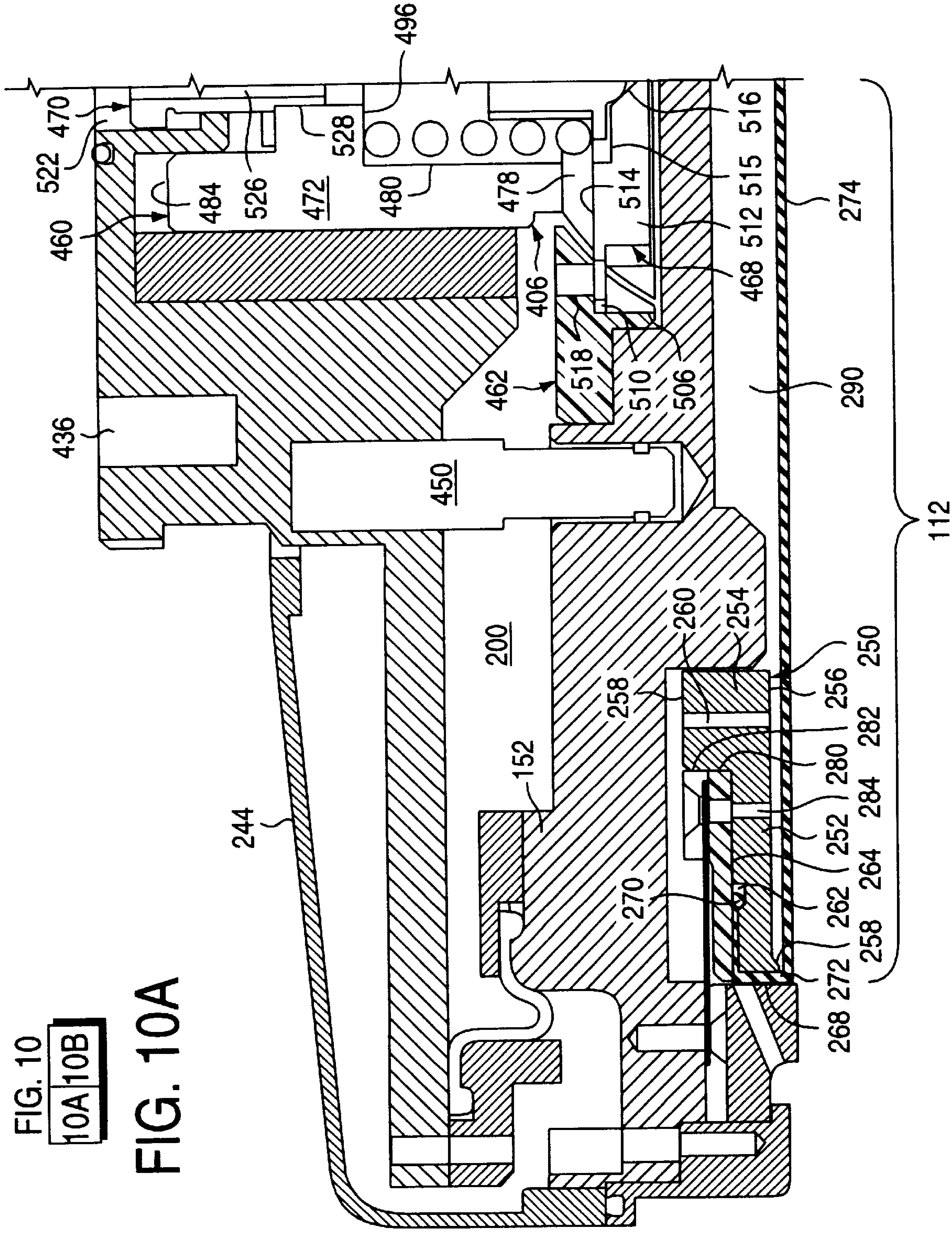
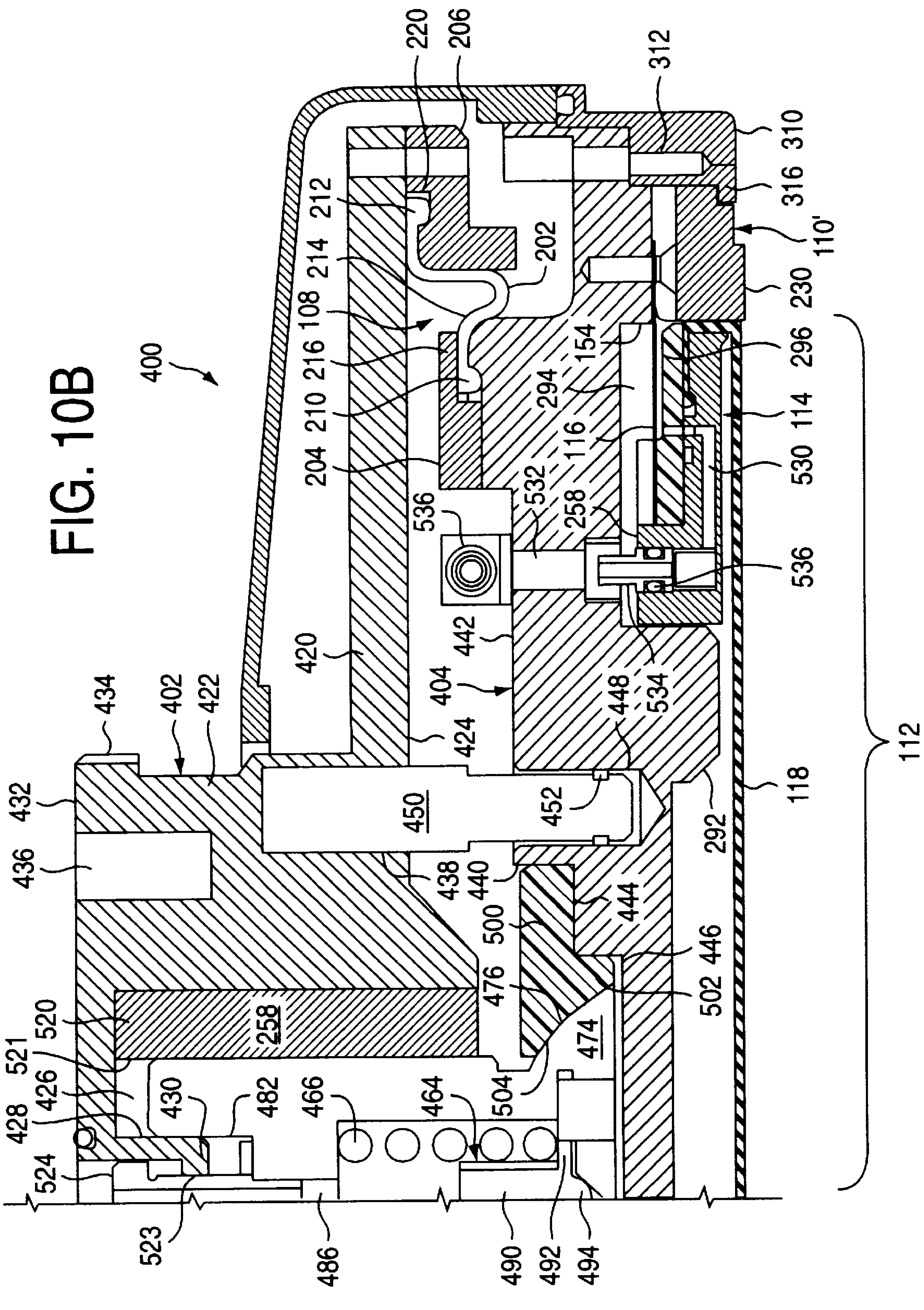



FIG. 10

| 10A | 10B |
|---|---|

FIG. 10A



400
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FIG. 10B

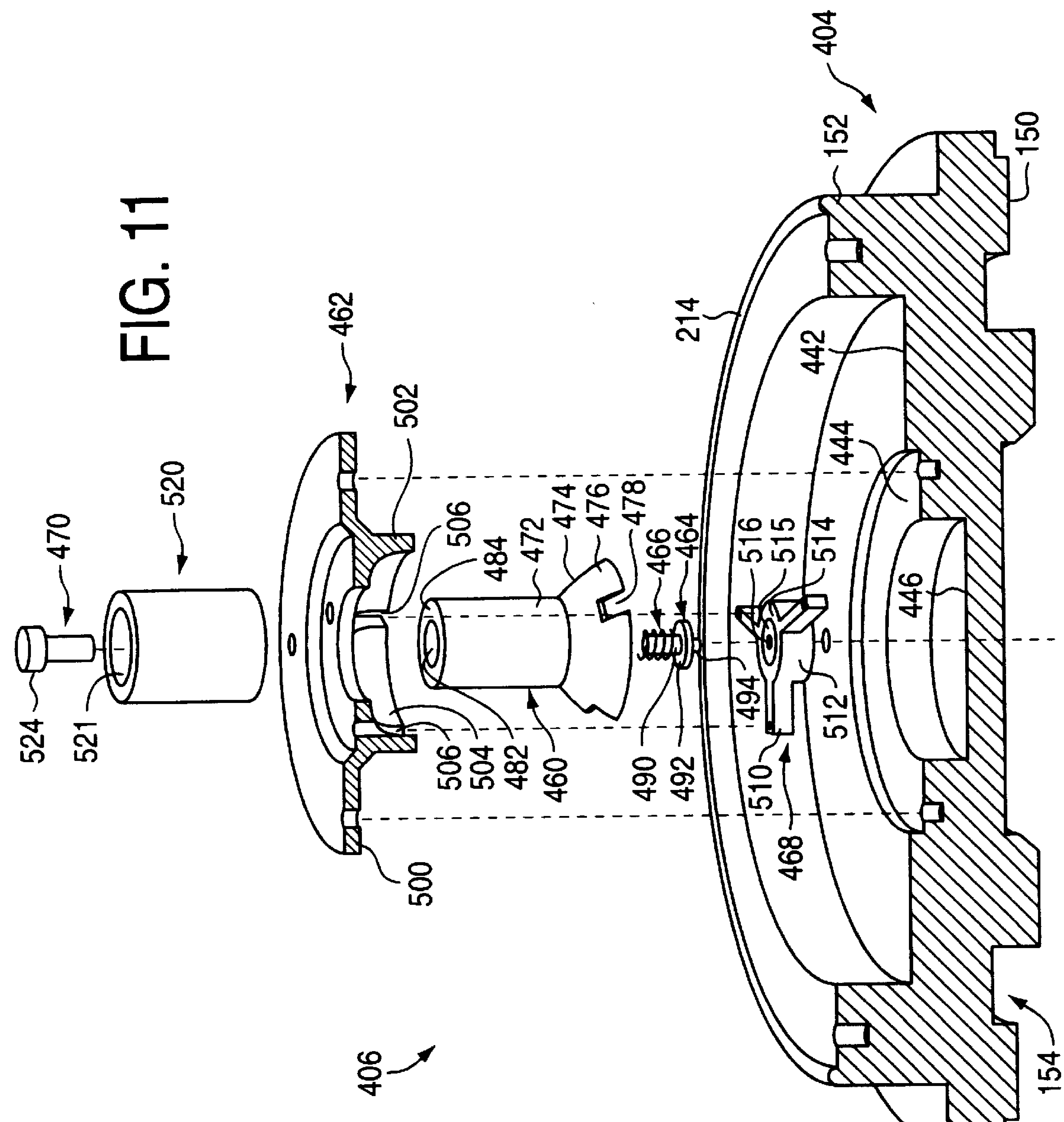

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FIG. 11

FIG. 12

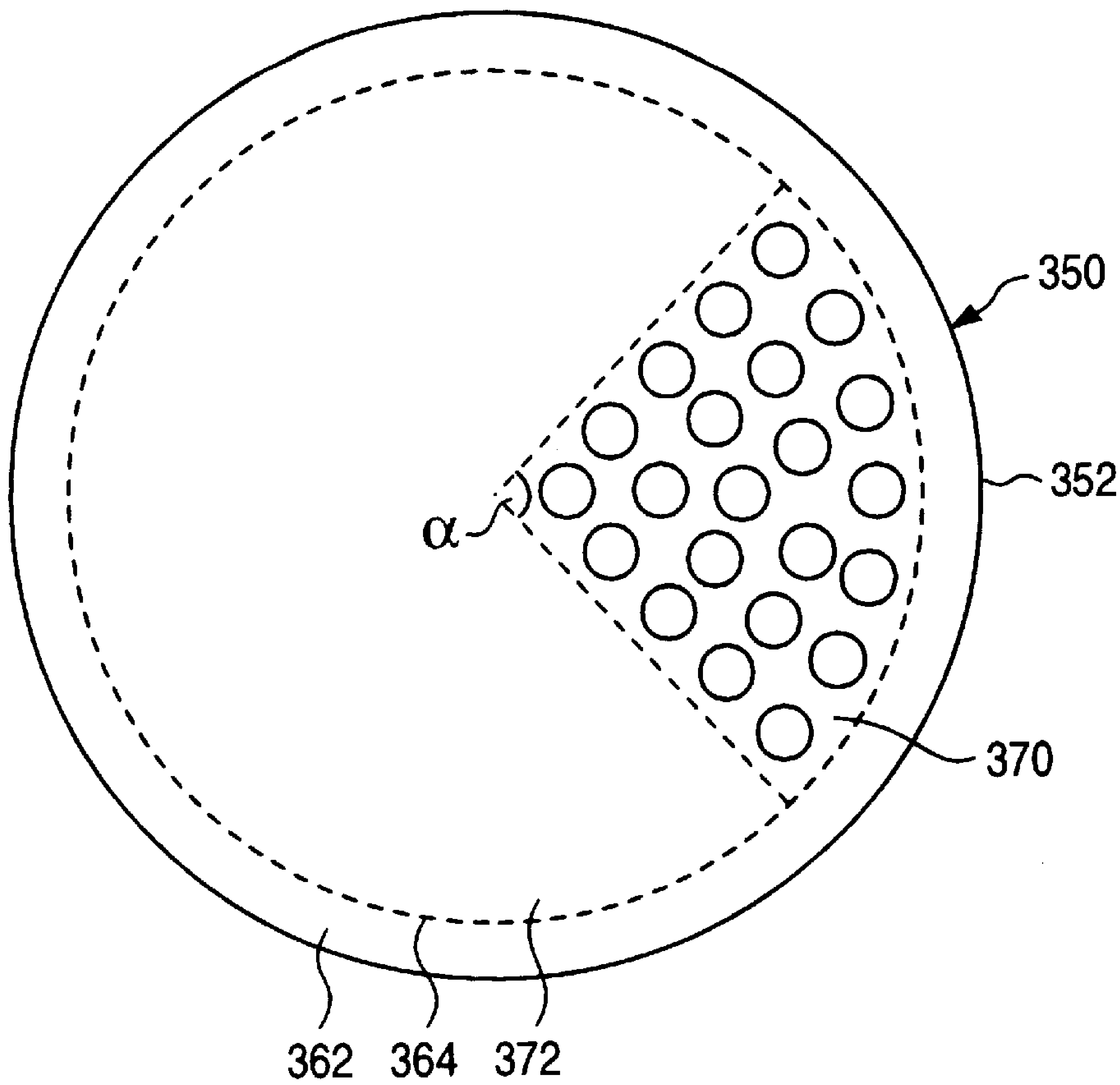
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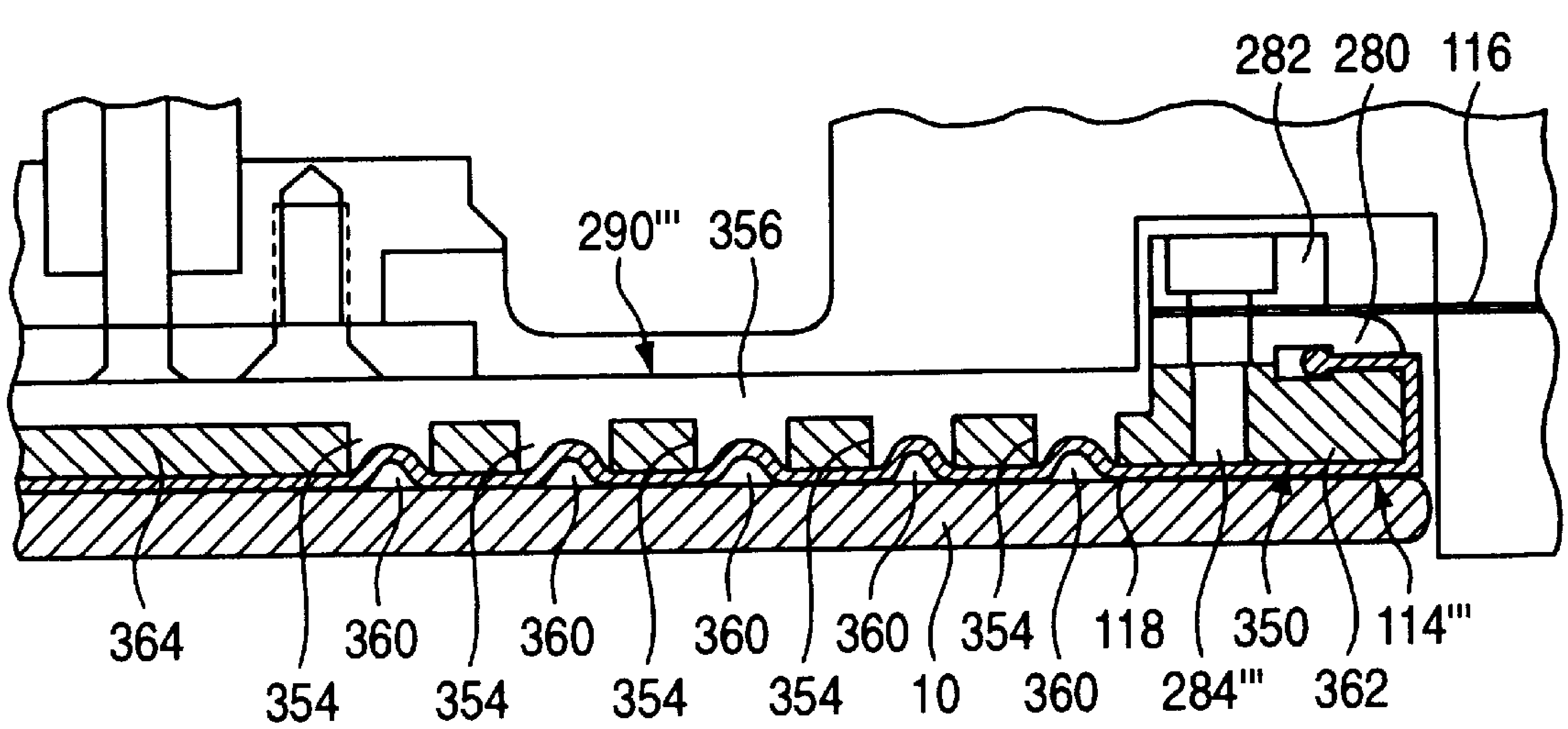
FIG. 13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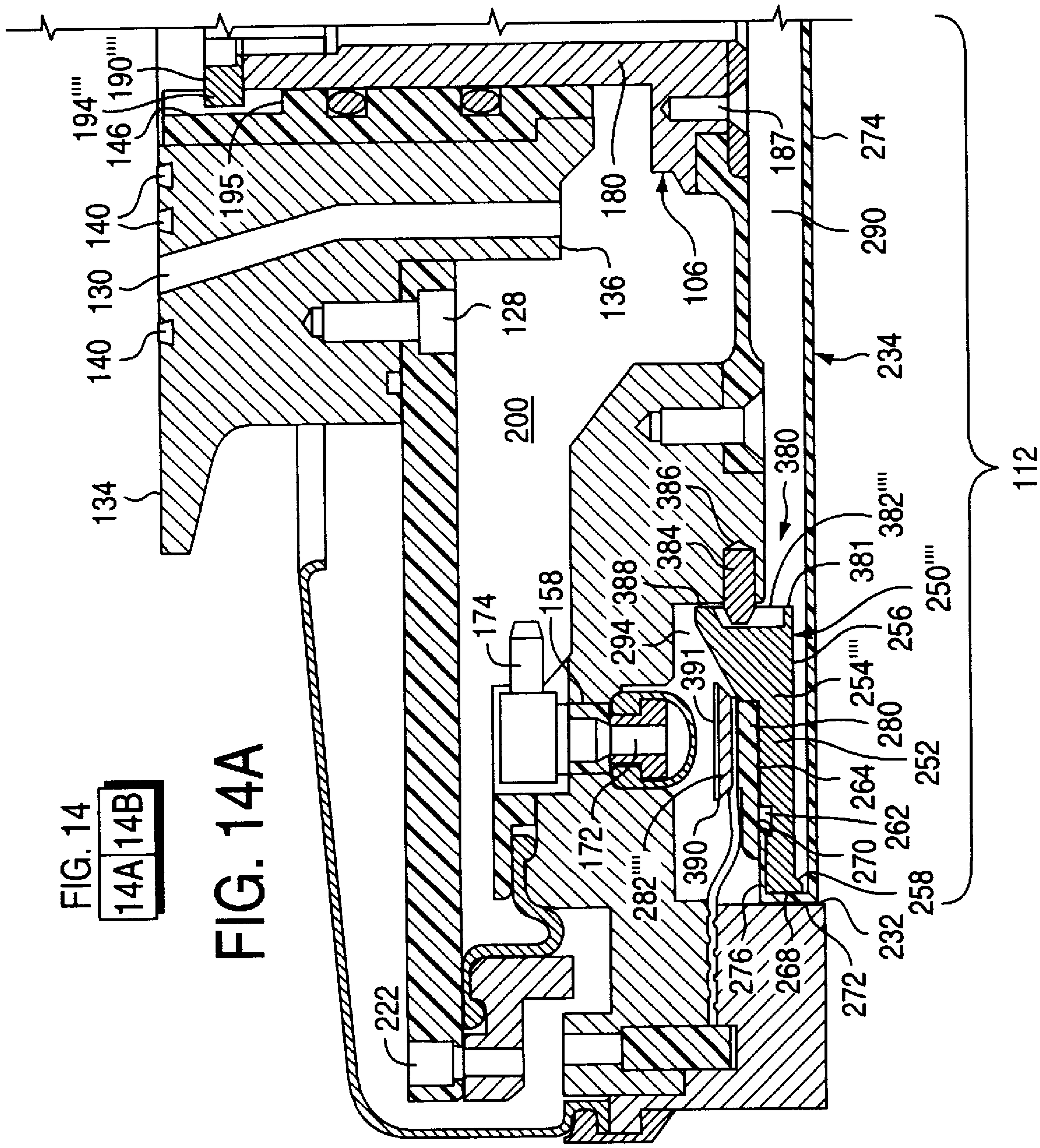
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386
384
388
382''''
381
250''''
256
294
391
254''''
280
252
264
262
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390
172
174
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222
112
FIG. 14
14A
14B

FIG. 14A

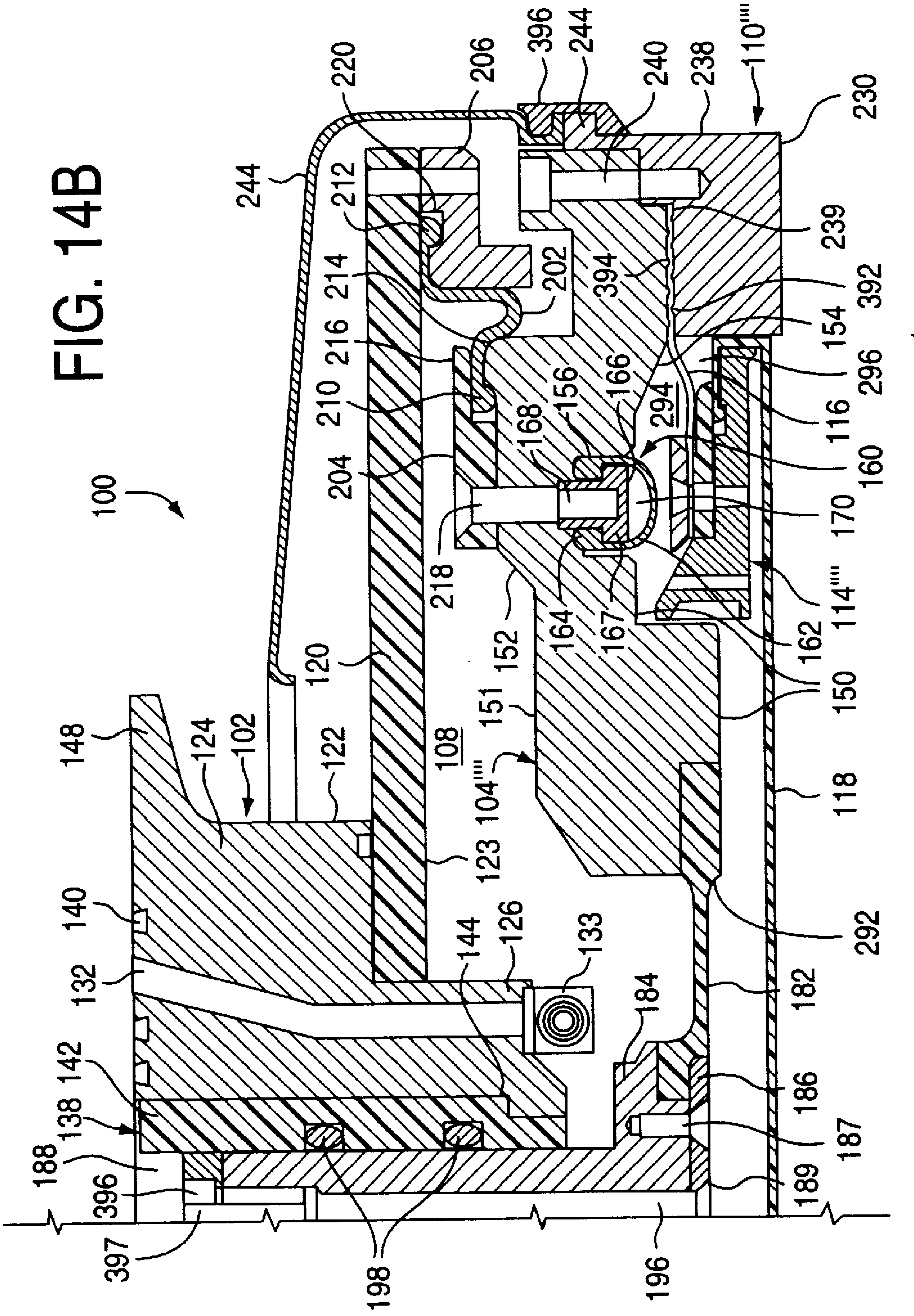

FIG. 14B

# CARRIER HEAD WITH A FLEXIBLE MEMBRANE FOR A CHEMICAL MECHANICAL POLISHING SYSTEM

This is a continuation of application Ser. No. 08/745,679, filed on Nov. 8, 1996, now abandoned.

## BACKGROUND OF THE INVENTION

The present invention relates generally to chemical mechanical polishing of substrates, and more particularly to a carrier head for a chemical mechanical polishing system.

Integrated circuits are typically formed on substrates, particularly silicon wafers, by the sequential deposition of conductive, semiconductive or insulative layers. After each layer is deposited, the layer is etched to create circuitry features. As a series of layers are sequentially deposited and etched, the outer or uppermost surface of the substrate, i.e., the exposed surface of the substrate, becomes increasingly non-planar. This non-planar outer surface presents a problem for the integrated circuit manufacturer. If the outer surface of the substrate is non-planar, then a photoresist layer placed thereon is also non-planar. A photoresist layer is typically patterned by a photolithographic apparatus that focuses a light image onto the photoresist. If the outer surface of the substrate is sufficiently non-planar, then the maximum height difference between the peaks and valleys of the outer surface may exceed the depth of focus of the imaging apparatus, and it will be impossible to properly focus the light image onto the outer substrate surface.

It may be prohibitively expensive to design new photolithographic devices having an improved depth of focus. In addition, as the feature size used in integrated circuits becomes smaller, shorter wavelengths of light must be used, resulting in a further reduction of the available depth of focus. Therefore, there is a need to periodically planarize the substrate surface to provide a substantially planar layer surface.

Chemical mechanical polishing (CMP) is one accepted method of planarization. This planarization method typically requires that the substrate be mounted to a carrier or polishing head. The exposed surface of the substrate is then placed against a rotating polishing pad. The carrier provides a controllable load, i.e., pressure, on the substrate to press it against the polishing pad. In addition, the carrier may rotate to provide additional motion between the substrate and polishing pad. A polishing slurry, including an abrasive and at least one chemically-reactive agent, may be distributed over the polishing pad to provide an abrasive chemical solution at the interface between the pad and substrate.

A CMP process is fairly complex, and differs from simple wet sanding. In a CMP process, the reactive agent in the slurry reacts with the outer surface of the substrate to form reactive sites. The interaction of the polishing pad and abrasive particles with the reactive sites results in polishing.

An effective CMP process has a high polishing rate and generates a substrate surface which is finished (lacks small-scale roughness) and flat (lacks large-scale topography). The polishing rate, finish and flatness are determined by the pad and slurry combination, the relative speed between the substrate and pad, and the force pressing the substrate against the pad. Because inadequate flatness and finish can create defective substrates, the selection of a polishing pad and slurry combination is usually dictated by the required finish and flatness. Given these constraints, the polishing rate sets the maximum throughput of the polishing apparatus.



The polishing rate depends upon the force pressing the substrate against the pad. Specifically, the greater this force, the higher the polishing rate. If the carrier head applies a non-uniform load, i.e., if the carrier head applies more force to one region of the substrate than to another, then the high pressure regions will be polished faster than the low pressure regions. Therefore, a non-uniform load may result in non-uniform polishing of the substrate.

An additional consideration in the production of integrated circuits is process and product stability. To achieve a high yield, i.e., a low defect rate, each successive substrate should be polished under substantially similar conditions. Each substrate should be polished by approximately the same amount so that each integrated circuit is substantially identical.

In view of the foregoing, there is a need for a chemical mechanical polishing apparatus which optimizes polishing throughput while providing the desired flatness and finish. Specifically, the chemical mechanical polishing apparatus should have a carrier head which applies a substantially uniform load across the substrate.

## SUMMARY OF THE INVENTION

In one aspect, the present invention is directed to a carrier head for a chemical mechanical polishing apparatus. The carrier head comprises a base, a support structure connected to the base by a flexure, and a flexible membrane connected to the support structure. The flexible membrane has a mounting surface for a substrate and extends beneath the support structure to define a chamber.

Implementations of the invention include the following. The flexure may be secured between an upper clamp and a lower clamp, and the membrane may be secured between the lower clamp and the support structure. The flexure may be substantially horizontal and annular, with an outer circumferential portion attached to the base and an inner circumferential portion attached to the support structure. The support structure may include an annular ring or a circular plate. A portion of the chamber above the plate may be connected by an aperture through the plate to a portion below. An outer edge of the support structure may have a downwardly projecting lip.

The carrier head may include one or more of the following: a housing connectable to a drive shaft to rotate therewith, a gimbal mechanism pivotally connecting the housing to the base to permit the base to pivot with respect to the housing, a retaining ring connected to the base and surrounding the flexible membrane, and a loading mechanism connecting the housing to the base to apply a downward pressure to the base. The housing may have a substantially vertical passage, and the gimbal mechanism may include a rod with its upper end slidable disposed in the passage. The gimbal mechanism may include a bearing base with a spherical outer surface connected to a lower end of the rod and a gimbal race with a spherical inner surface engaging the bearing base.

The support structure, flexure and membrane may be configured such that a downward pressure on the flexure is substantially balanced by an upward pressure on the support structure so that a downward pressure at the edge of the membrane is substantially the same as a downward pressure at other portions of the membrane. A surface area of the lower surface the support structure may be approximately equal to a surface area of the upper surface of the flexure. An outer diameter of the clamp may be less than an outer diameter of the support structure.

There may be a gap between the support structure and the flexure, and there may be a passage through the support structure to carrying a fluid into the gap to force a slurry out of the gap.

In another aspect, to a carrier head includes a housing, a base, a loading mechanism, and a gimbal mechanism. The gimbal mechanism includes a rod having an upper end slidably disposed in the passage in the housing, and a slightly flexible member connecting a lower end of the rod to the base.

Implementations of the invention include the following. The member may be a ring with an inner circumferential portion connected to the rod and an outer circumferential portion connected to the base. The member may be bendable vertically but is rigid radially. A stop may be connected to the upper end of the rod to limit downward travel of the base.

In another aspect, a carrier head includes a housing, a base, a loading mechanism connecting the housing to the base to control the vertical position of the base relative to the housing, and a cushion attached to a lower surface of the housing to stop an upward motion of the base.

In another aspect, the carrier head includes a base, a first flexible membrane, and a second flexible membrane. The first membrane has a mounting surface for a substrate and defines a first chamber. The second membrane is connected to the base and positioned above the first membrane to define a second chamber. The second membrane is positioned to exert a downward pressure on the first membrane when fluid is forced into the second chamber.

Implementations of the invention include the following. The first membrane may be attached to a support structure which is connected to the base by a flexure. The second membrane may be positioned to contact either the support structure or the first membrane. A support structure may be connected to the base by a flexure, and the first membrane may be attached to and extend beneath the support structure to define the first chamber. The support structure may include a support ring, and the second membrane may be positioned to extend through the center of the support ring to contact the first membrane. The carrier head may be used in a polishing apparatus with a first fluid supply connected to the first chamber, a second fluid supply connected to the second passage, and a sensor for measuring a pressure in the second chamber.

In another aspect, the carrier head includes a base, a support structure connected to the base by a flexure, a first membrane portion, and a second membrane portion. The first membrane portion is connected to and extends beneath the base to define a first substantially circular chamber. The second membrane portion is connect to and extends beneath the support structure to define a second substantially annular chamber surrounding the first chamber.

Implementations of the invention include the following. A lower surface of the first membrane portion may contact or be attached to an upper surface of the second membrane portion.

In another aspect, the carrier head has a support structure having a bottom face, a flexible membrane defining a chamber, and a port for applying a vacuum to the chamber. There is a recessed region in the bottom face of the support structure. The membrane is arranged and configured to be pulled into the recessed region if the chamber is evacuated to produce a reduced pressure area between the flexible membrane and an upper surface of a substrate. The recessed region distributed in an asymmetrical fashion.

In another aspect, the invention is directed to a method of sensing the presence of a substrate in a carrier head. A first chamber, formed by a first flexible membrane having a mounting surface for the substrate, is pressurized. A second chamber formed by a second flexible membrane to a first pressure is also pressurized. The second membrane is positioned to contact the first membrane above the mounting surface. The second chamber is sealed. A substrate is placed against the mounting surface, and fluid is forced out of the first chamber to create a reduced pressure region to chuck the substrate to the mounting surface. Then the pressure in the second chamber is measured a second time.

Implementations include the following. If the second pressure is greater than the first pressure, then the substrate may be indicated as present. If the second pressure is equal to the first pressure, the substrate may be indicated as missing.

In another aspect, the invention is directed to a method of chucking a substrate to a mounting surface of a carrier head. A substrate is positioned against a mounting surface of a carrier head. Fluid is forced into a first chamber defined by a first flexible membrane to apply a downward pressure to an annular area of substrate, and fluid is forced out of a second chamber defined by a second membrane to pull the second membrane upwardly and create a reduced pressure region bounded by the annular area to chuck the substrate to the mounting surface.

Implantations of the invention include the following. The first membrane may contact either the substrate, a support structure, or the second membrane. The first chamber may include an annular volume.

Advantages of the invention include the following. The carrier head applies a uniform load to the substrate. The carrier head is able to vacuum-chuck the substrate to lift it off the polishing pad.

Additional advantages of the invention will be set forth in the description which follows, and in part will be obvious from the description, or may be learned by practice of the invention. The advantages of the invention may be realized by means of the instrumentalities and combinations particularly pointed out in the claims.

## BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are incorporated in and constitute a part of the specification, schematically illustrate the present invention, and together with the general description given above and the detailed description given below, serve to explain the principles of the invention.

FIG. **1** is an exploded perspective view of a chemical mechanical polishing apparatus.

FIG. **2** is a schematic top view of a carousel, with the upper housing removed.

FIG. **3** is partially a cross-sectional view of the carousel of FIG. **2** along line **3**—**3**, and partially a schematic diagram of the pumps used by the CMP apparatus.

FIGS. **4**A & B schematic cross-sectional views of a carrier head in accordance with the present invention.

FIG. **5** is a schematic view of a substrate backing assembly in accordance with the present invention.

FIGS. **6**A & B are schematic, exploded and partially cross-sectional perspective views of the carrier head of FIGS. **4**A & B.

FIGS. **7**A & B are schematic cross-sectional views of a carrier head in which a bladder is positioned to directly contact a flexible membrane.

FIGS. **8**A and B are schematic cross-sectional views of a carrier head which includes two chambers.

FIGS. **9**A & B are schematic cross-sectional views of a carrier head in which a support plate is used in place of a support ring.

FIGS. **10**A and B are schematic cross-sectional views of a carrier head illustrating a gimbal mechanism including a gimbal body and a gimbal race.

FIG. **11** is an exploded and partially cross-sectional perspective view of the gimbal mechanism of FIG. **10**.

FIG. **12** is a bottom view of the support plate of the carrier head shown in FIG. **9**.

FIG. **13** is a schematic cross-sectional view of a carrier head illustrating the vacuum-chucking of a substrate.

FIGS. **14**A and B schematic cross-sectional views of a carrier head including a stop-pin assembly.

## DESCRIPTION OF THE PREFERRED EMBODIMENT(S)

Referring to FIG. **1**, one or more substrates **10** will be polished by a chemical mechanical polishing (CMP) apparatus **20**. A complete description of CMP apparatus **20** may be found in U.S. patent application Ser. No. 08/549,336, by Perlov, et al., filed Oct. 27, 1996, entitled CONTINUOUS PROCESSING SYSTEM FOR CHEMICAL MECHANICAL POLISHING, and assigned to the assignee of the present invention, the entire disclosure of which is hereby incorporated by reference.

According to the invention, CMP apparatus **20** includes a lower machine base **22** with a table top **23** mounted thereon and a removable upper outer cover (not shown). Table top **23** supports a series of polishing stations **25***a*, **25***b* and **25***c*, and a transfer station **27**. Transfer station **27** forms a generally square arrangement with the three polishing stations **25***a*, **25***b* and **25***c*. Transfer station **27** serves multiple functions of receiving individual substrates **10** from a loading apparatus (not shown), washing the substrates, loading the substrates into carrier heads (to be described below), receiving the substrates from the carrier heads, washing the substrates again, and finally transferring the substrates back to the loading apparatus.

Each polishing station **25***a*–**25***c* includes a rotatable platen **30** on which is placed a polishing pad **32**. If substrate **10** is an eight-inch (200 mm) diameter disk, then platen **30** and polishing pad **32** will be about twenty inches in diameter. Platen **30** is preferably a rotatable aluminum or stainless steel plate connected by a stainless steel platen drive shaft (not shown) to a platen drive motor (also not shown). For most polishing processes, the drive motor rotates platen **30** at about thirty to two-hundred revolutions per minute, although lower or higher rotational speeds may be used.

Polishing pad **32** may be a composite material with a roughened polishing surface. The polishing pad **32** may be attached to platen **30** by a pressure-sensitive adhesive layer. Polishing pad **32** may have a fifty mil thick hard upper layer and a fifty mil thick softer lower layer. The upper layer is preferably a material composed of polyurethane mixed with other fillers. The lower layer is preferably a material composed of compressed felt fibers leached with urethane. A common two-layer polishing pad, with the upper layer composed of IC-1000 and the lower layer composed of SUBA-4, is available from Rodel, Inc., located in Newark, Del. (IC-1000 and SUBA-4 are product names of Rodel, Inc.).

Each polishing station **25***a*–**25***c* may further include an associated pad conditioner apparatus **40**. Each pad conditioner apparatus **40** has a rotatable arm **42** holding an independently rotating conditioner head **44** and an associated washing basin **46**. The conditioner apparatus maintains the condition of the polishing pad so that it will effectively polish any substrate pressed against it while it is rotating.

A slurry **50** containing a reactive agent (e.g., deionized water for oxide polishing), abrasive particles (e.g., silicon dioxide for oxide polishing) and a chemically-reactive catalyzer (e.g., potassium hydroxide for oxide polishing), is supplied to the surface of polishing pad **32** by a slurry supply tube **52**. Sufficient slurry is provided to cover and wet the entire polishing pad **32**. Two or more intermediate washing stations **55***a* and **55***b* are positioned between neighboring polishing stations **25***a*, **25***b* and **25***c*. The washing stations rinse the substrates as they pass from one polishing station to another.

A rotatable multi-head carousel **60** is positioned above lower machine base **22**. Carousel **60** is supported by a center post **62** and rotated thereon about a carousel axis **64** by a carousel motor assembly located within base **22**. Center post **62** supports a carousel support plate **66** and a cover **68**. Multi-head carousel **60** includes four carrier head systems **70***a*, **70***b*, **70***c*, and **70***d*. Three of the carrier head systems receive and hold substrates and polish them by pressing them against the polishing pad **32** on platen **30** of polishing stations **25***a*–**25***c*. One of the carrier head systems receives a substrate from and delivers the substrate to transfer station **27**.

The four carrier head systems **70***a*–**70***d* are mounted on carousel support plate **66** at equal angular intervals about carousel axis **64**. Center post **62** allows the carousel motor to rotate the carousel support plate **66** and to orbit the carrier head systems **70***a*–**70***d*, and the substrates attached thereto, about carousel axis **64**.

Each carrier head system **70***a*–**70***d* includes a polishing or carrier head **100**. Each carrier head **100** independently rotates about its own axis, and independently laterally oscillates in a radial slot **72** formed in carousel support plate **66**. A carrier drive shaft **74** connects a carrier head rotation motor **76** to carrier head **100** (shown by the removal of one-quarter of cover **68**). There is one carrier drive shaft and motor for each head.

Referring to FIG. **2**, in which cover **68** of carousel **60** has been removed, carousel support plate **66** supports the four carrier head systems **70***a*–**70***d*. Carousel support plate includes four radial slots **72**, generally extending radially and oriented 90° apart. Radial slots **72** may either be close-ended (as shown) or open-ended. The top of support plate supports four slotted carrier head support slides **80**. Each slide **80** aligns along one of the radial slots **72** and moves freely along a radial path with respect to carousel support plate **66**. Two linear bearing assemblies bracket each radial slot **72** to support each slide **80**.

As shown in FIGS. **2** and **3**, each linear bearing assembly includes a rail **82** fixed to carousel support plate **66**, and two hands **83** (only one of which is illustrated in FIG. **3**) fixed to slide **80** to grasp the rail. Two bearings **84** separate each hand **83** from rail **82** to provide free and smooth movement therebetween. Thus, the linear bearing assemblies permit the slides **80** to move freely along radial slots **72**.

A bearing stop **85** anchored to the outer end of one of the rails **82** prevents slide **80** from accidentally coming off the end of the rails. One of the arms of each slide **80** contains an unillustrated threaded receiving cavity or nut fixed to the slide near its distal end. The threaded cavity or nut receives a worm-gear lead screw **86** driven by a slide radial oscillator motor **87** mounted on carousel support plate **66**. When motor

87 turns lead screw 86, slide 80 moves radially. The four motors 87 are independently operable to independently move the four slides along the radial slots 72 in carousel support plate 66.

A carrier head assembly or system, each including a carrier head 100, a carrier drive shaft 74, a carrier motor 76, and a surrounding non-rotating shaft housing 78, is fixed to each of the four slides. Drive shaft housing 78 holds drive shaft 74 by paired sets of lower ring bearings 88 and a set of upper ring bearings 89. Each carrier head assembly can be assembled away from polishing apparatus 20, slid in its untightened state into radial slot 72 in carousel support plate 66 and between the arms of slide 80, and there tightened to grasp the slide.

A rotary coupling 90 at the top of drive motor 186 couples two or more fluid or electrical lines 92*a*–92*c* into three or more channels 94*a*–94*c* in drive shaft 74. Three pumps 93*a*–93*c* may be connected to fluid lines 92*a*–92*c*, respectively. Channels 94*a*–94*c* and pumps 93*a*–93*c* are used, as described in more detail below, to pneumatically power carrier head 100 and to vacuum-chuck the substrate to the bottom of the carrier head. In the various embodiments of the carrier head described below, pumps 93*a*–93*c* remain coupled to the same fluid lines, although the function or purpose of the pumps may change.

During actual polishing, three of the carrier heads, e.g., those of carrier head systems 70*a*–70*c*, are positioned at and above respective polishing stations 25*a*–25*c*. Carrier head 100 lowers a substrate into contact with polishing pad 32, and slurry 50 acts as the media for chemical mechanical polishing of the substrate or wafer. The carrier head 100 uniformly loads the substrate against the polishing pad.

The substrate is typically subjected to multiple polishing steps, including a main polishing step and a final polishing step. For the main polishing step, usually performed at station 25*a*, carrier head 100 may apply a force of approximately four to ten pounds per square inch (psi) to substrate 10. At subsequent stations, carrier head 100 may apply more or less force. For example, for a final polishing step, usually performed at station 25*c*, carrier head 100 may apply a force of about three psi. Carrier motor 76 rotates carrier head 100 at about thirty to two-hundred revolutions per minute. Platen 30 and carrier head 100 may rotate at substantially the same rate.

Generally, carrier head 100 holds the substrate against the polishing pad and evenly distributes a downward pressure across the back surface of the substrate. The carrier head also transfers torque from the drive shaft to the substrate and ensures that the substrate does not slip from beneath the carrier head during polishing.

Referring to FIGS. 4–6, carrier head 100 includes a housing 102, a base 104, a gimbal mechanism 106, a loading mechanism 108, a retaining ring 110, and a substrate backing assembly 112. The housing 102 is connected to drive shaft 74 to rotate therewith about an axis of rotation 107 which is substantially perpendicular to the surface of the polishing pad. The loading mechanism 108 is positioned between housing 102 and base 104 to apply a load, i.e., a downward pressure, to base 104. The base 104 is fixed relative to polishing pad 32 by loading mechanism 108. Pressurization of a chamber 290 positioned between base 104 and substrate backing assembly 112 generates an upward force on the base and a downward force on the substrate backing assembly. The downward force on the substrate backing assembly presses the substrate against the polishing pad. The substrate backing assembly 112 includes a support structure 114, a flexure 116 connected between support structure 114 and base 104, and a flexible membrane 118 connected to support structure 114. The flexible membrane 118 extends below support structure 114 to provide a mounting surface 274 for the substrate. Each of these elements will be explained in greater detail below.

Housing 102 is generally circular in shape to correspond to the circular configuration of the substrate to be polished. The housing includes an annular housing plate 120 and a generally cylindrical housing hub 122. Housing hub 122 may include an upper hub portion 124 and a lower hub portion 126. The lower hub portion may have a smaller diameter than the upper hub portion. The housing plate 120 may surround lower hub portion 126 and be affixed to upper hub portion 122 by bolts 128. Both housing plate 120 and housing hub 122 may be formed of stainless steel or aluminum.

An annular cushion 121 may be attached, for example, by an adhesive, to a lower surface 123 of housing plate 120. Cushion 121 may fit into a recess 125 in the housing plate so that the cushion's bottom surface is flush with the lower surface of the housing plate. As discussed below, the cushion acts as a soft stop to limit the upward travel of base 104. Cushion 121 may be an open-cell pad, such as a fifty mil thick POLYTEX™ pad available from Rodel, Inc. of Newark, Del.

The housing hub 122 includes two passages 130 and 132 which connect an upper surface 134 of upper hub portion 124 to a lower surface 136 of lower hub portion 126. A fixture 133 for connecting a passage 132 to a flexible tube (not shown) in a fluid-tight manner may be mounted on lower surface 136 of lower hub portion 126. In addition, a central vertical bore 138 may extend along the central axis of the housing hub. O-rings 140 surround both passages 130 and 132, and central bore 138 to provide a fluid-tight seal when the carrier head is attached to the drive shaft. A cylindrical bushing 142 is press fit in central bore 138 and is supported by a ledge 144 formed in lower hub portion 126. Three slots 146 (only one of which is shown due to the cross-sectional view) are formed at equal angular intervals in the inner cylindrical surface of bushing 142. Bushing 142 may be a hard plastic material, such as a mixture of TEFLON™ and DELRIN™.

To connect housing 102 to drive shaft 74, carrier head 100 is then lifted so that two dowel pins (not shown) are fit into two dowel pin holes (not shown) in upper surface 134 of upper hub portion 124 and two paired dowel pin holes in drive shaft flange 96. This circumferentially aligns passages 130 and 132 with channels 94*a* and 94*b* (see FIG. 3). Central bore 138 will be aligned with central channel 94*c*. A flange 148 projects outwardly from upper hub portion 124 of housing 102. Flange 148 mates to flange 96 of drive shaft 74. A circular clamp (not shown) may clamp flange 148 to flange 96 to securely attach carrier head 100 to drive shaft 74.

Base 104 is a generally ring-shaped body located beneath the housing 102. The outer diameter of base 104 may be approximately the same as the outer diameter of housing plate 120, and the inner diameter of base 104 may be somewhat larger than the diameter of lower hub portion 126. A top surface 151 of the base includes an annular rim 152, and a lower surface 150 of base 104 includes an annular recess 154. An annular depression 156 may be formed in annular recess 152. The base 104 may be formed of a rigid material such as aluminum, stainless steel or a fiber-reinforced plastic.

A bladder **160** may be attached to a lower surface **150** of base **104**. Bladder **160** may include a membrane **162** and a clamp ring **166**. Membrane **162** may be a thin annular sheet of a flexible material, such as a silicon rubber, having protruding edges **164**. The clamp ring **166** may be an annular body having a T-shaped cross-section and including wings **167**. A plurality of holes, spaced at equal angular intervals, pass vertically through the clamp ring. As discussed below, one of these holes (on the left side of FIG. **4**) may be used as a passage **172** for pneumatic control of bladder **160**. The remainder of the holes may hold bolts to secure the clamp ring to the base. To assemble bladder **160**, protruding edges **164** of membrane **162** are fit above wings **167** of clamp ring **166**. The entire assembly is placed in annular depression **156**. Clamp ring **166** may be secured to base **104** by screws **168** (only one screw is shown on the right hand side of this cross-sectional view because the other hole is used as passage **172**). Clamp ring **166** seals membrane **162** to base **104** to define a volume **170**. A vertical passage **172** extends through clamp ring **166** and is aligned with a vertical passage **158** in base **104**. A fixture **174** may be inserted into passage **158**, and a flexible tube (not shown) may connect fixture **133** to fixture **174**.

Pump **93*b*** (see FIG. **3**) may be connected to bladder **160** via fluid line **92*b***, rotary coupling **90**, channel **94*b*** in drive shaft **74**, passage **132** in housing **102**, the flexible tube (not shown), passage **158** in base **104**, and passage **172** in clamp ring **166**. If pump **93*b*** forces a fluid, preferably a gas, such as air, into volume **170**, then bladder **160** will expand downwardly. On the other hand, if pump **93*b*** evacuates fluid from volume **170**, then bladder **160** will contract. As discussed below, bladder **160** may be used to apply a downward pressure to support structure **114** and flexible membrane **118**.

Gimbal mechanism **106** permits base **104** to move with respect to housing **102** so that the base may remain substantially parallel with the surface of the polishing pad. Specifically, the gimbal mechanism permits the base to move vertically, i.e., along axis of rotation **107**, and to pivot, i.e., to rotate about an axis parallel to the surface of the polishing pad, with respect to housing **102**. However, gimbal mechanism **106** prevents base **104** from moving laterally, i.e., along an axis parallel to the polishing pad, with respect to the housing. Gimbal mechanism **106** is unloaded; that is, no downward pressure is applied from the housing through the gimbal mechanism to the base. However, the gimbal mechanism can transfer any side load, such as the shear force created by the friction between the substrate and polishing pad, to the housing.

Gimbal mechanism **106** includes a gimbal rod **180**, a flexure ring **182**, an upper clamp **184**, and a lower clamp **186**. The upper end of gimbal rod **180** fits into a passage **188** through cylindrical bushing **142**. The lower end of gimbal rod **180** is attached to upper clamp **184**. Alternatively, upper clamp **184** may be formed as an integral part of gimbal rod **180**. The inner edge of flexure ring **162** is held between lower clamp **186** and upper clamp **184**, whereas the outer edge of flexure ring **182** is secured to the lower surface **150** of base **104**. Screws **187** may be used to secure lower clamp **186** to upper clamp **184**, and screws **187** may be used to secure flexure ring **182** to base **104**. Gimbal rod **180** may slide vertically along passage **188** so that base **104** may move vertically with respect to housing **102**. However, gimbal rod **180** prevents any lateral motion of base **104** with respect to housing **102**.

Gimbal rod **180**, upper clamp **184** and lower clamp **186** are formed of rigid materials, such as stainless steel or aluminum. However, flexure ring **182**, as its name implies, is formed of a moderately flexible material. The flexure ring material is selected to be able to withstand high strains, induced by pivoting of the base with respect to the housing, without breaking, and to have a moderate elastic modulus. The flexure ring **182** is sufficiently elastic that the carrier can undergo small pivoting motions without substantially changing the load distribution on the retaining ring. However, the flexure ring is sufficiently rigid that it effectively transmits the side load from the base to housing. The flexure ring is not as flexible as membrane **162** or membrane **118**. Specifically, flexure ring **182** should be flexible enough to permit base **104** to pivot so that one edge of the base is approximately five to ten mils higher than the edge of the opposite base. The flexure ring may be formed of a hard plastic, such as DELRIN™, available from Dupont of Wilmington, Del. Alternately, the flexure ring may be formed of a laminate of glass fibers and epoxy resin, such as G10. Flexure ring **182** may bend slightly in the vertical direction, but is rigid in the radial direction.

A stop **190** is secured to a top surface **191** of the gimbal rod by three screws **192** (only one of which is shown due to the cross-sectional view). Three pins **194** (again, only one pin is shown) project horizontally from stop **190** and fit into the three slots **146** in bushing **142**. Pins **194** are free to slide vertically, but not laterally, in slots **146**. Thus, base **104** can move vertically relative to housing **102** without affecting the rotation of the carrier head. In addition, because gimbal rod **180** is free to slide in passage **188**, pressure cannot be applied from housing **102** to base **104** through the gimbal mechanism. Stop **190** also limits the downward travel of base load **104** to prevent over-extension of the carrier head. Pins **194** will catch against the bottom ledge **195** of vertical slot **146** to halt the downward travel of the base.

Gimbal mechanism **106** may also include a vertical passage **196** formed along the central axis of the stop, the gimbal rod, the upper clamp, and the lower clamp. Passage **196** connects upper surface **134** of housing hub **122** to a lower surface of lower clamp **186**. O-rings **198** may be set into recesses in bushing **142** to provide a seal between gimbal rod **180** and bushing **142**.

The vertical position of base **104** relative to housing **102** is controlled by loading mechanism **108**. The loading mechanism includes a chamber **200** located between housing **102** and base **104**.

Chamber **200** is formed by sealing base **104** to housing **102**. The seal includes a diaphragm **202**, an inner clamp ring **204**, and an outer clamp ring **206**. Diaphragm **202**, which may be formed of a sixty mil thick silicone sheet, is generally ring-shaped, with a flat middle section, a protruding inner edge **210** and a protruding outer edge **212**. Inner edge **210** of diaphragm **202** rests on rim **152** of base **104**, with inner edge **210** fitting over a ridge **214** which runs along the outer edge of rim **152**.

Inner clamp ring **204** is used to seal diaphragm **202** to base **104**. The inner clamp ring rests primarily on rim **152** and has an outer lip **216** which projects over ridge **214**. Inner clamp ring **204** is secured to base **104**, for example, by bolts **218**, to firmly hold the inner edge of diaphragm **202** against base **104**.

Outer clamp ring **206** is used to seal diaphragm **202** to housing **102**. The protruding outer edge **212** of diaphragm **202** rests in a groove **220** on an upper surface of outer clamp ring **206**. Outer clamp ring **206** is secured to housing plate **120**, e.g., by bolts **222**, to hold the outer edge of diaphragm **202** against the bottom surface of housing plate **120**. Thus, the space between housing **102** and base **104** is sealed to form chamber **200**.

Pump **93***a* (see FIG. **3**) may be connected to chamber **200** via fluid line **92***a*, rotary coupling **90**, channel **94***a* in drive shaft **74**, and passage **130** in housing **102**. Fluid, preferably a gas such as air, is pumped into and out of chamber **200** to control the load applied to base **104**. If pump **93***a* pumps fluid into chamber **200**, the volume of the chamber will increase and base **104** will be pushed downwardly. On the other hand, if pump **93***a* pumps fluid out of chamber **200**, the volume of chamber **200** will decrease and base **104** will be pulled upwardly.

The optional cushion **121** may be positioned in housing plate **120** directly above inner clamp ring **204**. Cushion **121** acts as a soft stop to halt the upward motion of base **104**. Specifically, when chamber **200** is evacuated and base **104** moves upwardly, the inner clamp ring **204** abuts against cushion **121**. This prevents any sudden jarring motions which might cause a vacuum-chucked substrate to detach from the carrier head.

When drive shaft **74** rotates housing **102**, diaphragm **202** also rotates. Because diaphragm **202** is connected to base **104** by inner clamp ring **204**, the base will rotate. In addition, because support structure **114** is connected to base **104** by flexure **116**, the support structure and attached flexible membrane will also rotate.

Retaining ring **110** may be secured at the outer edge of the base **104**. Retaining ring **110** is a generally annular ring having a substantially flat bottom surface **230**. When fluid is pumped into chamber **200** and base **104** is pushed downwardly, retaining ring **110** is also pushed downwardly to apply a load to polishing pad **32**. An inner surface **232** of retaining ring **110** defines, in conjunction with mounting surface **274** of flexible membrane **118**, a substrate receiving recess **234**. The retaining ring **110** prevents the substrate from escaping the receiving recess and transfers the lateral load from the wafer to the base.

Retaining ring **110** may be made of a hard plastic or a ceramic material. Retaining ring **110** may be secured to base **104** by, for example, bolts **240**. In addition, retaining ring **110** may include one or more passages **236** connecting the inner surface **232** to an outer surface **238**. As discussed below, passages **236** provide pressure equilibrium between the outside of the carrier head and a gap between the flexure and the support structure in order to ensure free vertical movement of the support structure.

Retaining ring **110** may also include an annular rim **242** which fits around the outer circumference of base **104**. A shield **244** may be placed over carrier head **100** so that it rests on rim **242** of retaining ring **110** and extends over housing plate **120**. Shield **244** protects the components in carrier head **100**, such as diaphragm **202**, from contamination by slurry **50**.

The substrate backing assembly **112** is located below base **104**. Substrate backing assembly **112** includes support structure **114**, flexure **116** and flexible membrane **118**. The flexible membrane **118** connects to and extends beneath support structure **114**. In conjunction with base **104**, support structure **114**, flexure **116**, and gimbal mechanics on **106**, flexible membrane **118** defines a chamber **290**. Support structure **114** and attached flexible membrane **118** are suspended from base **104** by flexure **116**. The support structure **114** may fit into the space formed by annular recess **154** formed in base **104** and retaining ring **110**.

Support structure **114** includes a support ring **250**, an annular lower clamp **280**, and an annular upper clamp **282**. Support ring **250** is a rigid member which may have an annular outer portion **252** and a thicker annular inner portion **254**. Support ring **250** may have a generally planar lower surface **256** with a downwardly-projecting lip **258** at its outer edge. One or more passages **260** may extend vertically through inner portion **254** of support ring **250** connecting lower surface **256** to an upper surface **266** of the inner portion. An annular groove **262** may be formed in an upper surface **264** of outer portion **252** of the support ring. Support ring **250** may be formed of aluminum or stainless steel.

Flexible membrane **118** is a circular sheet formed of a flexible and elastic material, such as a high-strength silicone rubber. Membrane **118** may have a protruding outer edge **270**. A portion **272** of membrane **118** extends around a lower corner of support ring **250** at lip **258**, upwardly around an outer surface **268** of outer portion **252**, and inwardly along an upper surface **264** of outer portion **252**. Protruding edge **270** of membrane **118** may fit into groove **262**. The edge of flexible membrane **118** is clamped between lower clamp **280** and support ring **250**.

The flexure **116** is a generally planar annular ring. Flexure **116** is flexible in the vertical direction, and may be flexible or rigid in the radial and tangential directions. The material of flexure **116** is selected to have a durometer measurement between 30 on the Shore A scale and 70 on the Shore D scale. The material of flexure **116** may be a rubber such as neoprene, an elastomeric-coated fabric such as NYLON™ or NOMEX™, a plastic, or a composite material such as fiberglass. Flexure **116** should be somewhat more flexible than the flexure ring **182**, but may be approximately as flexible as flexible membrane **118**. Specifically, flexure **116** should allow support structure **114** to move vertically by about one-tenth of an inch. The outer edge of flexure **116** is secured between lower surface **150** of base **104** and retaining ring **110**. The inner edge of flexure **116** is secured between lower clamp **280** and upper clamp **282**. Flexure **116** projects inwardly from its attachment point into recess **154**. Annular upper clamp **282**, annular lower clamp **280** and support ring **250** may be secured together by screws **284** to assemble support structure **114**.

The space between flexible membrane **118**, support structure **114**, flexure **116**, base **104**, and gimbal mechanism **106** defines chamber **290**. Passage **196** through gimbal rod **180** connects chamber **290** to the upper surface of housing **102**. Pump **93***c* (see FIG. **3**) may be connected to chamber **290** via fluid line **92***c*, rotary coupling **90**, channel **94***c* in drive shaft **74** and passage **196** in gimbal rod **180**. If pump **93***c* forces a fluid, preferably a gas such as air, into chamber **290**, then the volume of the chamber will increase and flexible membrane **118** will be forced downwardly. On the other hand, if pump **93***c* evacuates air from fluid chamber **290**, then the volume of the chamber will decrease and the membrane will be forced upwardly. It is preferred to use a gas rather than a liquid because a gas is more compressible.

The lower surface of flexible membrane **118** provides a mounting surface **274**. During polishing, substrate **10** is positioned in substrate receiving recess **234** with the backside of the substrate positioned against the mounting surface. The edge of the substrate may contact the raised lip **258** of support ring **114** through flexible membrane **118**.

By pumping fluid out of chamber **290**, the center of flexible membrane **118** may be bowed inwardly and pulled above lip **258**. If a substrate is positioned against mounting surface **274**, the upward deflection of flexible membrane **118** will create a low pressure pocket between the membrane and the substrate. This low pressure pocket will vacuum-chuck the substrate to the carrier head.

Carrier head **100** provides independently controllable loads to the substrate and the retaining ring. The downward pressure of flexible membrane **118** against substrate **10** is controlled by the pressure in chamber **290**. The downward pressure of retaining ring **110** against polishing pad **32** is controlled by both the pressure in chamber **200** and the pressure in chamber **290**. Specifically, the load on retaining ring **110** is equal to the pressure in chamber **290** subtracted from the pressure in chamber **200**. If the pressure in chamber **290** is greater than the pressure in chamber **200**, no load will be applied to retaining ring **110**. The independently controllable loads permit optimization of the retaining ring load in order to minimize the edge effect, as described in U.S. patent application Ser. No. 08/667,221, filed Jun. 19, 1996, by Guthrie, et al., entitled METHOD AND APPARATUS FOR USING A RETAINING RING TO CONTROL THE EDGE EFFECT, and assigned to the assignee of the present invention, the entire disclosure of which is hereby incorporated by reference.

Flexure **116** improves the uniformity of the load applied by flexible membrane **118** to substrate **10**. Specifically, because support structure **114** may pivot and move vertically relative to base **104** and housing **102**, the support structure may remain substantially parallel to the surface of the polishing pad. Because flexible membrane **118** is connected to support structure **114**, the flexible membrane will also remain substantially parallel to the surface of the polishing pad. Therefore, the flexible membrane may adjust to a tilted polishing pad without deforming the portion of the membrane near the edge of the substrate. Consequently, the load on the substrate will remain uniform even if the polishing pad is tilted with respect to the carrier head. Flexible membrane **118** may deform to match the backside of substrate **10**. For example, if substrate **10** is warped, flexible membrane **118** will, in effect, conform to the contours of the warped substrate. Thus, the load on the substrate will remain uniform even if there are surface irregularities on the backside of the substrate.

In addition, the load to substrate **10** will remain substantially uniform even at differing pressures. Specifically, flexure **116** permits support structure **114** and flexible membrane **118** to move vertically relative to base **104**. When fluid is pumped into chamber **290**, flexure **116** will deflect downwardly, increasing the volume of the chamber. Because the flexible membrane moves with the support structure **114**, this vertical motion does not deform the edge of the flexible membrane. Consequently, the corner of flexible membrane **118** at the lower edge of support ring **114** will apply substantially the same load as the remainder of the flexible membrane.

The flexure **116** prevents support structure **114** and flexible membrane **118** from rotating with respect to base **104**. Flexure **116** transfers any torque load, such as the frictional force from the rotating polishing pad **32**, to base **104**, which, in turn, transfers the load to housing **102** through gimbal mechanism **106**. As base **104** rotates, flexure **116** also rotates, forcing support structure **114** and flexible membrane **118** to rotate thereby, causing substrate **10** to rotate with carrier drive shaft **74**.

Furthermore, flexure **116**, support structure **114** and flexible membrane **118** are configured and arranged so that the presence of flexure **116** does not create an additional downward pressure at the edge of the flexible membrane. From its attachment point at lower surface **150** of base **104**, flexure **116** projects inwardly into annular recess **154**. A part of structure **114** extends outwardly underneath flexure **116** beyond its attachment point to the flexure. Support structure **114** and flexure **116** are configured so that the surface area of lower surface **256** of support ring **250** is approximately equal to the total surface area of the upper surface **268** of support ring **250**, annular upper clamp **282**, and flexure **116**. Since chamber **290** extends around both upper surface **258** and lower surface **256**, the same pressure is applied by the chamber to the upper and lower surfaces. Thus, a downward pressure on the flexure plus the weight of the support structure is substantially balanced by an upward pressure on the support ring. The passages **260** through support ring **250** provide pressure equilibrium between a portion **294** of chamber **290** that is located above the support structure and the remainder of chamber **290**.

There is a gap **296** between support structure **114** and the lower surface of flexure **116**. Annular lower clamp **280** may be configured so that gap **296** has a wide portion, preferably near the outer edge of the support structure. For example, the lower clamp need not extend all the way to outer surface **268** of support ring **250**. With this configuration, when chamber **290** is pressurized during polishing, flexure **116** may expand into the wide portion of gap **296** without contacting support structure **114**. Since the free portion of the flexure does not contact the support structure, at least a portion of the downward pressure on the flexure is transferred to retaining ring **110** rather than support structure **114**. This reduces the load on support structure **114** sufficiently so that, as discussed above, the downward pressure on the flexure plus the weight of the support structure is substantially balanced by an upward pressure on the support ring.

The passages **236** through retaining ring **110** can provide pressure equilibrium between gap **296** and the atmosphere outside of polishing head **100**. This ensures that air can be vented from the gap so that support structure **114** is free to move vertically.

A carrier head of polishing apparatus **20** may operate as follows. Substrate **10** is loaded into substrate receiving recess **234** with the backside of the substrate abutting mounting surface **274** of flexible membrane **118**. Pump **93*b*** pumps fluid into bladder **160**. This causes bladder **160** to expand and force support structure **114** downwardly. The downward motion of support structure **114** causes lip **258** to press the edge of flexible membrane **118** against the edge of substrate **10**, creating a fluid-tight seal at the edge of the substrate. Then pump **93*c*** evacuates chamber **290** to create a low-pressure pocket between flexible membrane **118** and the backside of substrate **10** as previously described. Finally, pump **93*a*** pumps fluid out of chamber **200** to lift base **104**, substrate backing assembly **112**, and substrate **10** off a polishing pad or out of the transfer station. Carousel **60** then, for example, rotates the carrier head to a polishing station. Pump **93*a*** then forces a fluid into chamber **200** to lower the substrate **10** onto the polishing pad. Pump **93*b*** evacuates volume **170** so that bladder **160** no longer applies a downward pressure to support structure **114** and flexible membrane **118**. Finally, pump **93*c*** may pump a gas into chamber **290** to apply a downward load to substrate **10** for the polishing step.

In the alternate embodiments of the carrier head discussed below, elements with modified functions or operations will be referred to with primed reference numbers. Elements which are merely changed in size or shape will be referred to with unprimed reference numbers. For example, certain of the carrier heads discussed below are configured for polishing a six-inch (**150** millimeters) diameter substrate. The changes to the size and shape of the elements to accommodate polishing of a six-inch substrate will not be discussed in detail, nor will elements changed for that purpose be referred to with primed reference numbers.

In addition, as discussed above, in the embodiments discussed below, although pumps **93***a*–**93***c* remain coupled to fluid lines **92***a*–**92***c*, respectively, the purpose or function of the pumps may change. In particular, the pumps may be connected to different pressure chambers in the different embodiments of the carrier head.

Referring to FIG. **7**, in another embodiment, in which similar parts are referred to with primed reference numbers, bladder **160'** is positioned beneath base **104** so that membrane **162'** may directly contact an upper surface **300** of flexible membrane **118**.

Carrier head **100'** vacuum-chucks substrates in a fashion similar to that of the carrier head of FIG. **4**. Specifically, substrate **10** is inserted into substrate receiving recess **234** with the backside of the substrate abutting mounting surface **274** of flexible membrane **118**. Pump **93***b* pumps air into volume **170'** to inflate bladder **160'**. This causes membrane **162'** to apply a downward pressure directly to an annular portion of upper surface **300** of flexible membrane **118'**. This creates a fluid-tight seal between the flexible membrane and the substrate. Then pump **93***c* may evacuate fluid out of chamber **290** to create a low pressure pocket and vacuum-chuck the substrate to the carrier head.

There are several benefits of using bladder **160'**. Bladder **160'** provides a soft and deformable backing for flexible membrane **118'**. Therefore when the chamber is evacuated and flexible membrane **118'** is pulled inwardly to form the low-pressure pocket, the edge of the pocket will have a gentle slop. Because there is no hard edge to create stress on the substrate, the substrate is less likely to fracture during the chucking process. In addition, the depth of the suction cup is controllable. Once substrate **10** is chucked to the carrier head, bladder **160'** may be inflated or deflated. If bladder **160'** is inflated, membrane **118'** and substrate **10** will be pushed downwardly, whereas if bladder **160'** is deflated, membrane **118'** and substrate **10** will be pulled upwardly.

One problem that has been encountered in chemical mechanical polishing is that the attachment of the substrate to the carrier head may fail, and the substrate may detach from the carrier head. If this occurs, the operator may not be able to visually observe that the carrier head no longer carries the substrate. In this situation, a CMP apparatus will continue to operate even though the substrate is no longer being polished. This wastes time and decreases throughput. In addition, a loose substrate, i.e. one not attached to a carrier head, may be knocked about by the moving components of the CMP apparatus, potentially damaging the CMP apparatus itself or leaving debris which may damage other substrates.

A CMP apparatus utilizing carrier head **100'** may be operated to sense the presence of a substrate. If the CMP apparatus detects that the substrate is missing from the carrier head, the apparatus may alert the operator and automatically halt polishing operations to avoid wasted time and potential damage.

Referring to FIG. **3**, apparatus **20** may include a valve **302** and a pressure gauge **304** placed in a fluid line **92***b* between rotary coupling **90** and pump **93***b*. Valve **302** and gauge **304** are shown in shadow because these elements are not used in conjunction with the embodiment of the carrier head previously described. When valve **302** is closed, volume **170'** is sealed from pump **93***b* and pressure gauge **304** may measure the pressure in bladder **160'**.

Returning to FIG. **7**, apparatus **20** senses whether the carrier head successfully chucked the substrate as follows. The substrate is loaded into substrate receiving recess **234** so that the backside of the substrate contacts mounting surface **274**. Pump **93***b* inflates bladder **160'** to form a seal between flexible membrane **118** and substrate **10**. Then valve **302** is closed to seal volume **170'**. Pressure gauge **304** is used to measure the pressure in bladder **160**. Then, pump **93***c* evacuates chamber **290'** to create a low pressure pocket between the flexible membrane and the substrate. Finally, pump **93***a* evacuates chamber **200** to lift substrate **10** off of the polishing pad. Pressure gauge **304** then makes another measurement of the pressure in bladder **160'** to determine whether the substrate was successfully vacuum-chucked to the carrier head.

On one hand, if the substrate is present, then the low pressure pocket created between the flexible membrane and the substrate will create an upward force on the substrate. This upward force will cause the substrate to press upwardly on membrane **162'**. This will reduce the volume of bladder **160'** and thereby increase the pressure in volume **170'**. On the other hand, if a substrate is not present in the carrier head, then no upward force will be applied to the membrane and the pressure in volume **170'** will remain constant. Therefore, if pressure gauge **304** measures a pressure increase concurrent with pump **93***c* pumping air out of chamber **290'**, the CMP apparatus has successfully vacuum-chucked the substrate to the carrier head. Pressure gauge **304** may also be used to continuously monitor the pressure within volume **170'** to detect the presence of the substrate in the carrier head. If pressure gage **304** detects a decrease in the pressure of volume **170'**, e.g., while transporting the substrate between polishing stations or between a polishing station and a transfer station, then this is an indication that the substrate has detached from the carrier head. In this circumstance, operations may be halted and the CMP operator alerted of the problem.

Carrier head **100'** also utilizes a different method to attach the retaining ring to the base. Retaining ring **110'** may be secured to base **104** by a retaining piece **310**. The retaining piece **310** may be secured to base **104** by screws **312**. The retaining piece may catch in a projecting ledge **314** of retaining ring **110'** with an annular lip **316**.

Referring to FIG. **8**, in another embodiment, in which similar parts are referred to with double primed reference numbers, carrier head **100"** includes a generally circular inner chamber **320** and a generally annular outer chamber **322** surrounding inner chamber **320**.

In the carrier head of FIG. **8**, substrate backing assembly **112"** includes support structure **114**, flexure **116**, and flexible membrane **118"**. The flexible membrane **118"** may include an upper membrane or membrane portion **324** and a lower membrane or membrane portion **326**. Lower membrane **326** is connected to support structure **114**, whereas upper membrane **324** is connected directly to base **104**. The upper membrane **324** defines inner chamber **320**, whereas outer membrane **326** defines outer chamber **322**. Flexible membrane **118"** may be formed of a flexible and elastic material, such as a high strength silicone rubber.

Upper membrane **324** may be a circular sheet of a material, such as a high-strength silicone rubber. Inner membrane **324** may have a protruding outer edge **328**. The outer edge **328** of upper membrane **324** may be captured between an annular wing **332** of an annular clamp ring **330** and a rim **334** on flexure ring **182"**. Clamp ring **330** may be secured in a recess **336** between flexure ring **182"** and base **104** by bolts **168"**. The clamp ring presses the inner membrane against the flexure ring to form a fluid-tight seal. The space between upper membrane **324** and gimbal mechanism **106** defines generally circular upper chamber **320**.

Lower membrane **326** may also be a circular sheet of material. Lower membrane **326** may have a protruding lower edge **338**. The attachment of outer membrane **326** to support structure **114** is similar to the attachment of flexible membrane **118** to support structure **114** in FIG. **4**. Specifically, outer edge **338** is secured in groove **262** and clamped between lower clamp **280** and support ring **250**. The space between lower membrane **326**, inner membrane **324**, base **104**, flexure **116**, and support structure **114** defines generally annular outer chamber **322**.

The portion of membrane **118**" below chamber **320** provides a circular inner portion of the substrate mounting surface, whereas the portion of membrane **118**" below chamber **322** provides an annular outer portion of the substrate mounting surface. A bottom surface **340** of inner membrane **324** may be attached, e.g., by an adhesive, to a top surface **342** of outer membrane **326**. Alternately, upper membrane **324** and lower membrane **326** may be different portions of a single lower membrane.

Pump **93***c* may be connected to inner chamber **320** by fluid line **92***c*, rotary coupling **90**, channel **94***c* in drive shaft **74**, and passage **196** in gimbal mechanism **106**. Similarly, pump **92***b* may be connected to outer chamber **322** by fluid line **92***b*, rotary coupling **90**, channel **94***b* in drive shaft **74**, passage **132** in housing **102**, a flexible fluid connector (not shown), passage **158** in base **104**, and a passage **344** in clamp ring **330**.

Carrier head **100**" may vacuum-chuck and sense the presence of substrate **10** in the carrier head in a fashion similar to that of the carrier head of FIG. **7**. Specifically, during the vacuum-chucking process, pump **92***b* may pump fluid into outer chamber **322**, causing the outer annular portion of membrane **118**" to press directly against substrate **10** to form a fluid-tight seal. Then valve **302** (see FIG. **3**) is closed and a first measurement of the pressure in outer chamber **322** is taken by gauge **304**. Then pump **93***c* evacuates inner chamber **320** to create a low-pressure pocket to vacuum-chuck the substrate. If the substrate is successfully vacuum-chucked, the pressure measured by gauge **304** should increase.

Another problem that has been encountered in chemical mechanical polishing is that the edge of the substrate is often polished at a different rate (usually faster, but occasionally slower) than the center of the substrate. This may occur even if the load is uniformly applied to the substrate. To compensate for this effect, inner chamber **320** and outer chamber **322** may apply different loads to the substrate during polishing. For example, if the edge of the substrate is polishing more slowly than the center, the pressure within outer chamber **322** may be made greater than the pressure within inner chamber **320** thereby increasing polishing rate at the substrate edge. By selecting the relative loads, more uniform polishing of the substrate may be achieved.

The carrier head **100**' of FIG. **7** may also be used to apply different loads to the edge and center of the substrate. To create a pressure differential between the center and edge of the substrate, bladder **160**' begins in a deflated state and chamber **290** is pressurize to a desired pressure. Then bladder **160**' is inflated so that membrane **162**' contacts the upper surface **300** of flexible membrane **118**. This effectively seals an annular outer portion of **304** of chamber **290** from a circular inner portion **302** of chamber **290**. To increase the pressure on the center of the substrate vis-a-vis the edge, pump **93***c* may force fluid into circular inner portion **302**. Because outer portion **304** is sealed by bladder **160**', its pressure does not change. To decrease the pressure on the center of the substrate vis-a-vis the edge, pump **93***c* may evacuate inner portion **302** after bladder **160**' forms the seal.

Since membrane **162**' is not bonded or clamped to flexible membrane **118**, the seal created by bladder **160**' may not be completely fluid-tight. Therefore, fluid may gradually leak between the membranes until portions **302** and **304** have the same pressure. Thus, it may be necessary to periodically perform the procedure described above.

Referring to FIG. **9**, in another embodiment, in which similar parts referred to with triple primed reference numbers, substrate backing assembly **112**''' includes a support plate **350** rather than a support ring.

Support plate **350** is a generally disk-shaped body. As part of support structure **114**''', the entire support plate may move vertically and pivot with respect to base **104**. Annular lower clamp **280** and annular upper clamp **282** may be secured to an edge portion **362** of the support plate by bolts **284**'''.

Support plate **350** has a generally planar lower surface **352**. Support plate **350** is suspended in chamber **290**''' by flexure **116**. A plurality of apertures **354** extend vertically through a center portion **364** of the support plate to connect lower surface **352** to an upper surface **360**. Apertures **354** connect a portion **356** of chamber **290**''' located above the support plate to a portion **358** of chamber **290**''' located below the support plate. Alternately, lower surface **352** of support plate **350** may have a recessed region, with a single aperture connecting chamber portion **356** to chamber portion **358**.

Flexible membrane **118** is clamped between support plate **350** and lower clamp **280**, and extends beneath the lower surface of the support plate. When pump **93***c* evacuates chamber **290**''', flexible membrane **118** is pulled upwardly against support plate **350** and into apertures **354**. If the backside of the substrate is placed against mounting surface **274**, then the extension of the flexible membrane into the apertures creates a plurality of low-pressure pockets **360** between the substrate and the flexible membrane (see FIG. **13**). These low-pressure pockets vacuum-chuck the substrate to the carrier head.

One problem encountered in the CMP process is difficulty in removing the substrate from the polishing pad. As previously discussed, a thin layer of slurry is supplied to the surface of the polishing pad. When the substrate contacts the polishing pad, the surface tension of the slurry generates an adhesive force which binds the substrate to the polishing pad. If this surface tension holding the substrate on the polishing pad is greater than the force holding the substrate on the carrier head, then when the carrier head retracts, the substrate will remain on the polishing pad.

One arrangement for reliably removing the substrate from the polishing pad is shown in FIG. **12**. As shown in FIG. **12**, the distribution of apertures **354** across lower surface **352** may be asymmetric rather than radially symmetric. That is, the support plate may include an area **370** with apertures and an area **372** without apertures. Area **370** may be generally wedge-shaped, with an angle a between 45° and 180°. Area **370** may also be located only near the edge of portion **364** of support plate **350**, rather than extending to the center of the support plate.

During the vacuum-chucking of the substrate, the asymmetrical distribution of apertures **354** results in an asymmetrical application of an upward force to the substrate. The asymmetrical force creates a torque on the substrate which tends to preferentially lift one edge of the substrate away from the polishing pad. This reduces the adhesive force due to the slurry surface tension, and improves the reliability of vacuum-chucking the substrate to the carrier head.

Referring to FIG. **14**, in another embodiment, in which similar parts are referred to with quadruple primed reference numbers, the carrier head includes a stop pin assembly **380** to limit the downward motion of support structure **114**"".

In the carrier head of FIG. **14**, inner portion **254**"" of support ring **250**"" has a generally wedged-shaped cross-section. An inner surface **381** of the wedged-shaped inner portion has an annular recess **382** formed therein. Three or more stop pins **384** (only one of which is shown due to the cross-sectional view), positioned at equal annular intervals, fit into holes **386** in base **104**"". The stop pins **384** project outward horizontally and into angular recess **382** in support ring **250**"". If fluid is pumped into chamber **290**, thereby forcing support structure **114** downwardly, an upper rim **388** of support ring **250**"" may catch against stop pins **384** to limit the downward travel of the support structure.

The annular upper clamp **282**"" includes one or more radial grooves **390** (only one is shown) in upper surface **391**. When bladder **160** is inflated and membrane **162** contacts annular upper clamp **282**"", radial grooves **390** form channels between the portions of volume **294** of chamber **290** located on either side of bladder. The separation of volume **294** into two separate portions is not shown in FIG. **14** (because the substrate backing assembly **112** is shown in a lowered position for polishing), but can be seen in FIG. **4**. These channels permit pressure equilibrium to ensure uniform polishing.

An upper surface **239** of retaining ring **110**" may have a series of concentric circular ridges **392**. An outer annular area of lower surface **150** of base **104**"" may also include a series of concentric circular ridges **394**. When the carrier head is assembled, with retaining ring **110**"" attached to base **104**"", ridges **392** will mate to ridges **394** and pinch the outer circumferential portion of flexure **116** therebetween. This provides an improved clamp which prevents the flexure from slipping.

The gimbal mechanism may include a Y-shaped stop **190**"" with three arms **194**"". Stop **190**"" may be connected to top surface **191** of gimbal rod **180** with a single central bolt **396**. The central bolt **396** may have a vertical passage **397** therethrough to provide a fluid connection between upper surface **134** of housing **102** and passage **196** in gimbal rod **180**.

An annular seal **396** with a C-shaped cross section may be used to hold shield **244** on rim **242** of retaining ring **110**"".

Referring to FIGS. **10** and **11**, in another embodiment, a carrier head **400** includes a gimbal mechanism **406** which includes a gimbal body **460** and a gimbal race **462** rather than a flexure ring. Due to the substantial changes in the housing, base and gimbal mechanisms, these parts will be referred to with new reference numbers. In contrast, except as discussed below, the loading mechanism, retainer ring, and substrate backing assembly are similar to the components discussed with reference to FIG. **4**, and will be referred to with unprimed reference numbers.

Carrier head **400** includes a housing **402**, a base **404**, a gimbal mechanism **406**, loading mechanism **108**, retaining ring **110**, and substrate backing assembly **112**.

Housing **402** includes a housing plate **420** and an integrally-attached housing hub **422**. A cylindrical cavity **426** is formed in bottom surface **424** of housing **402**. A cylindrical plastic bushing **520** fits into cylindrical cavity **426** with its outer surface abutting housing **402**. A circular flange **428** with an inwardly-turned lip **430** projects downwardly from a top surface **432** of housing hub **422** into cavity **426**. Housing hub **422** may also have a threaded neck **434** and two vertical dowel pin holes **436**. A threaded perimeter nut **98** (see FIG. **3**) may fit over flange **96** and be screwed onto threaded neck **434** of housing hub **432** to secure carrier head **400** to drive shaft **74**.

Housing **402** may include two torque pin holes **438** formed in its bottom surface **424** which project upwardly into housing hub **422**. In addition, two passages (not shown in this cross-sectional view) also connect top surface **432** of housing hub **422** to bottom surface **424**.

Base **404** is generally disk-shaped, with a basin **440** formed in an upper surface **442** thereof. Basin **440** has a flat annular surface **444** surrounding a flat-bottom depression **446**. Two torque pin holes **448** may be found in upper surface **442** of base **404** surrounding basin **440**.

Two vertical torque pins **450** are used to transfer torque from housing **402** to base **404**. The torque pins **450** fit securely into torque pin holes **438** in housing **402** and project downwardly into receiving torque pin holes **448** in base **404**. Torque pins **450** are free to slide vertically in receiving torque pin holes **448**, but O-rings **452** hold each torque pin **450** in place laterally. Thus, base **404** is free to move vertically relative to housing **402**, but if housing **402** rotates, then the torque pins will force the base to rotate as well. The O-rings **452** are sufficiently elastic to permit a slight pivoting of base **404** relative to housing **402**.

Gimbal mechanism **406** is designed to allow base **404** to pivot, i.e. rotate about an axis parallel to the surface to the polishing pad and normal to axis of rotation **107**, with respect to housing **402**. Specifically, base **404** may pivot about a point located on the surface of polishing pad **32**. Gimbal mechanism **402** includes a gimbal body **460**, a gimbal race **462**, a guide pin **464**, a spring **466**, a biasing member **468**, and a stop **470**.

Gimbal body **460** includes a cylindrical gimbal rod **472** which projects upward from a bearing base **474**. Bearing base **474** includes a spherical outer surface **476** with three radial slots **478** (only one is shown in the cross-sectional view of FIG. **10**) which extend from the edge of outer surface **476** to gimbal rod **472**. The lower surface of bearing base **474** has a Y-shaped depression (not shown) which contains biasing member **468** when gimbal mechanism **406** is fully assembled. A cylindrical recess **480** may be formed in the bottom surface of gimbal body **460**, and another cylindrical recess **482** may be formed in a top surface **484** of gimbal rod **472**. Recesses **480** and **482** may be connected by a vertical passage **486**.

Guide pin **464** includes a guide rod **490**, a disk **492** which projects radially outwardly from the lower end of guide rod **490**, and a spherical projection **494** on the bottom of disk **492**. Spring **466** fits into recess **480** in the bottom of gimbal rod **472**, and guide rod **490** of guide pin **464** fits inside spring **466**. When the gimbal mechanism is assembled, the spring is compressed between the top of disk **492** and the upper portion **496** of recess **480**.

Gimbal race **462** fits around gimbal body **460** and rests on base **404**. Gimbal race **462** may include a flat outer portion **500** which rests on annular surface **444** and a wedge-shaped inner portion **502** which fits into depression **446**. A spherical inner surface **504** of wedge-shaped portion **502** engages the spherical outer surface **476** of bearing base **474**. Three notches **506** may be cut into inner surface **504** of gimbal race **462**. Gimbal race **462** may be secured to base **404** with screws (not shown) which pass through outer piece **500** and into receiving threaded recesses in the base.

The biasing member **468** is generally Y-shaped, and includes three arms **510** which project outwardly from a central section **512**. The top surface **514** of central section **512** has a circular recess **515** and a conical depression **516** at the center of the recess. The biasing member **468** fits into the Y-shaped depression (not shown) on the underside of bearing base **474**. The disk **492** of guide pin **464** fits into recess **515** with its spherical projection **494** engaging conical depression **516** of biasing member **468**. The arms **510** of biasing member **468** extend through slots **478** in bearing base **474** and into notches **506** in gimbal race **462**. Bolts or screws **518** may be used to secure arms **510** to gimbal race **462**.

Once gimbal mechanism **406** is assembled, gimbal race **462** is secured to base **404**, and biasing member **468** is secured to gimbal race **462**. Guide pin **464** contacts biasing member **468**, and spring **466** urges gimbal body **460** upwardly away from the biasing member so that spherical outer surface **476** of bearing base **474** is pressed against spherical inner surface **504** of gimbal race **462**. The gimbal rod **472** of gimbal mechanism **406** engages an inner surface **521** of bushing **520**. The gimbal body **460** is free to slide vertically in cavity **426** relative to housing **402** and to pivot in two dimensions relative to gimbal race **462**. When the gimbal pivots, arms **510** will slide in slots **478**. However, because biasing member **468** is fixed to gimbal race **462**, the downward force from spring **466** is not transmitted to carrier base **404**. Because there is no outward pressure on the center of the base due to spring **466**, the lower surface of the base remains substantially planar when gimbal mechanism **406** is attached.

Stop pin **470**, which has a threaded lower portion **528**, fits into a stop pin hole **522** defined by downwardly projecting flange **428**. The stop pin extends through an aperture **523** at the bottom of the stop pin hole and is screwed into passage **486** of gimbal rod **472**. The recess **482** in gimbal rod **472** fits around flange **428**. A head **524** of stop pin **470** catches against lip **430** of flange **428** to limit the downward motion of gimbal mechanism **406** and base **404** relative to housing **402**. The stop pin **470** may also include a vertical passage **526** to connect top surface **432** of housing **422** to passage **486** in gimbal rod **472**. Pump **93***c* (see FIG. **3**) may be connected via fluid line **92***c*, rotary coupling **90**, central conduit **94***c* in drive shaft **74**, passage **526** in stop pin **470**, passage **486** and recess **480** in gimbal body **460**, and slot **478** to chamber **200**. Thus, in the embodiment of FIG. **10**, pump **93***c* is used to control the vertical actuation of the carrier head.

Carrier head **400** may also include a slurry purge mechanism to flush slurry out from gap **296** between flexure **116** and support structure **114**. The slurry purge mechanism includes a passageway **530** which extends vertically from upper surface **258** of inner portion **254** of support ring **250**, radially outwardly into outer portion **252**, and upwardly through lower clamp **280** of gap **296**.

The slurry purge mechanism may also include a vertical passage **532** extending through base **404**. A fixture **536** may be connected to the passage **532** at upper surface **442** of base **404**. A fitting **534** may connect passageway **530** in base **404** to passage **532** in support ring **250**. The fitting **534** may be fixedly connected to base **404**, project downwardly through volume **294** of chamber **290**, and be slidably disposed in passageway **530** of support ring **114**. The fitting **534** may be sealed in passageway **530** by O-rings **538**.

Pump **93***b* may be connected to passageway **530** via fluid line **92***b*, rotary coupling **90**, channel **94***b* in drive shaft **74**, a passage through housing **402** (not shown), a flexible fluid coupling (also not shown) such as a plastic tube, passageway **532** in base **404**, and fitting **534**. Pump **92***b* may force a liquid, e.g. deionized water, through passageway **530** to flush slurry from gap **296**.

Pump **93***a* may be connected to chamber **290** via fluid line **92***a*, rotary coupling **90**, channel **94***a* in drive shaft **74**, a passage through housing **402** (not shown), a flexible fluid coupling (not shown), and a passage through base **404** (also not shown). Pump **93***a* may be used to control the pressure in chamber **290**.

In summary, the carrier head of the present invention suspends a support structure from the base of a carrier head by means of a flexure. A flexible membrane is connected to and extends below the support structure to define a chamber. By pressurizing the chamber, an even load can be applied across the substrate. In addition, the flexure allows the support structure, and thus the entire flexible membrane, to pivot and move vertically with respect to the base. Thus, the load is applied more uniformly across the entire back side of the substrate.

The present invention has been described in terms of the preferred embodiment. The invention, however, is not limited to the embodiments depicted and described. Rather, the scope of the invention is defined by the appended claims.

What is claimed is:

**1**. A carrier head for a chemical mechanical polishing apparatus, comprising:

a base;

a retaining ring connected to the base;

a support structure connected to the base by a flexure to be moveable independently of the base and the retaining ring; and

a flexible membrane that defines a boundary of a pressurizable chamber, the membrane connected to the support structure and having a mounting surface for a substrate.

**2**. The carrier head of claim **1** wherein the support structure includes a support body, an upper clamp and a lower clamp, and wherein the flexure is secured between the upper clamp and the lower clamp and the membrane is secured between the lower clamp and the support body.

**3**. The carrier head of claim **1** wherein the flexure extends over an outer circumferential portion of the support structure, and a gap separates the flexure from the outer circumferential portion of the support structure.

**4**. The carrier head of claim **3** wherein the base has a passageway fluidly coupling the gap to an outer surface of the base.

**5**. The carrier head of claim **1** wherein the flexure has an outer circumferential portion attached to the base and an inner circumferential portion attached to the support structure.

**6**. The carrier head of claim **1** wherein the support structure includes an annular ring.

**7**. The carrier head of claim **6** wherein the flexible membrane extends around an outer rim of the annular ring.

**8**. The carrier head of claim **6** wherein the chamber includes a first portion located above the annular ring and a second portion located below the annular ring.

**9**. The carrier head of claim **1** wherein the support structure includes a circular plate.

**10**. The carrier head of claim **9** wherein the chamber includes a first portion located above the circular plate and a second portion located below the circular plate.

**11**. The carrier head of claim **10** wherein the circular plate includes an aperture to connect the first portion of the chamber to the second portion of the chamber.

12. The carrier head of claim **11** wherein the circular plate includes a plurality of apertures.

13. The carrier head of claim **9** wherein the flexible membrane extends around an outer rim of the circular plate.

14. The carrier head of claim **1** wherein the membrane is configured to be pulled toward the support structure if the chamber is evacuated.

15. The carrier head of claim **1** wherein the membrane is configured to be urged away from the support structure if the chamber is pressurized.

16. The carrier head of claim **1** wherein the flexible membrane extends beneath a lower surface of the support structure and around an outer surface of the support structure.

17. A carrier head for a chemical mechanical polishing apparatus, comprising:

a base;

a support structure connected to the base by a flexure; and

a flexible membrane having a mounting surface for a substrate, the membrane connected to and extending beneath the support structure to define a boundary of a chamber that includes a first portion located above the support structure and a second portion located below the support structure.

18. The carrier head of claim **17** wherein the support structure has a passageway to connect the first portion of the chamber to the second portion of the chamber.

19. A carrier head for a chemical mechanical polishing apparatus, comprising:

a base;

a support structure connected to the base by a flexure, wherein an outer edge of the support structure includes a downwardly-projecting lip; and

a flexible membrane that defines a boundary of a pressurizable chamber, the membrane connected to the support structure and extending beneath the support structure and around the lip and having a mounting surface for a substrate.

20. A carrier head for a chemical mechanical polishing apparatus, comprising:

a base;

a support structure;

a flexure connecting the base to the support structure;

a flexible membrane having a mounting surface for a substrate, the membrane connected to and extending beneath the support structure to define, in conjunction with an inner surface of the base, an inner surface of the support structure and an inner surface of the flexure, a chamber; and

the support structure, flexure and membrane configured such that a downward pressure on the flexure is substantially balanced by an upward pressure on the support structure so that a downward pressure on the substrate at the edge of the membrane is substantially the same as a downward pressure on the substrate at other portions of the membrane.

21. The carrier head of claim **20** wherein the flexure extends over at least a portion of the support structure.

22. The carrier head of claim **21** wherein the flexure includes an outer circumferential portion attached to the base and an inner circumferential portion attached to the support structure.

23. The carrier head of claim **21** wherein a surface area of a lower surface of the portion of the support structure that forms a second boundary of the chamber is approximately equal to a total surface area of an upper surface of the flexure and an upper surface of the support structure that form a third boundary of the chamber.



24. The carrier head of claim **20** wherein the support structure includes a support body and a clamp, and wherein the flexible membrane extends above a portion of the support body to be secured between the support body and the clamp.

25. The carrier head of claim **24** wherein an outer diameter of the clamp is less than an outer diameter of the support body, so that a portion of the flexible membrane includes an exposed upper surface.

26. The carrier head of claim **20**, wherein an edge of the membrane extends around a corner of the support structure.

27. A carrier head for a chemical mechanical polishing apparatus, comprising:

a base;

a support structure;

a flexure connecting the base to the support structure to permit relative vertical movement, there being a gap between the flexure and the support structure;

a flexible membrane having a mounting surface for a substrate, the membrane connected to and extending beneath the support structure to define a boundary of a chamber; and

a passage connected to the gap for introducing a fluid into the gap to force a slurry out of the gap.

28. The carrier head of claim **27** wherein the passage includes a channel through the support structure fluidly coupling the chamber to the gap.

29. The carrier head of claim **28** wherein the passage further includes a channel through the base.

30. The carrier head of claim **29** wherein the passage further includes a fitting positioned in the chamber to fluidly couple the channel through the support structure to the channel through the base.

31. The carrier head of claim **27** further comprising a channel through a housing and a flexible fluid connector to fluidly couple the channel through the housing to the passage.

32. A carrier head for positioning a substrate on a polishing surface, comprising:

a housing connectable to a drive shaft to rotate therewith;

a base;

a gimbal mechanism pivotally connecting the housing to the base to permit the base to pivot with respect to the housing;

a support structure movably connected to the base;

a flexible membrane having a mounting surface for a substrate, the membrane connected to the support structure and extending beneath the base to define a boundary of a pressurizable chamber; and

a retaining ring fixedly secured to the base to pivot with the base and surrounding the mounting surface.

33. The carrier head of claim **32** wherein the gimbal mechanism includes a vertical passage to connect a top surface of the housing to the chamber.

34. The carrier head of claim **32** wherein the support structure is movably connected to the base by a flexure that has an outer circumferential portion attached to the base and an inner circumferential portion attached to the support structure.

35. The carrier head of claim **32** further comprising a loading mechanism positioned between the housing and the base to apply a downward pressure to the base.

36. The carrier head of claim **32** wherein the housing includes a substantially vertical passage and the gimbal mechanism includes a shaft having an upper end slidably disposed in the passage.

37. The carrier head of claim **36** wherein the gimbal mechanism includes a bearing base with a spherical outer surface connected to a lower end of the shaft, and the gimbal mechanism further includes a gimbal race with a spherical inner surface connected to the base, the outer surface of the bearing base engaging the inner surface of the gimbal race.

38. The carrier head of claim **36** wherein the gimbal mechanism includes a flexible member connecting a lower end of the shaft to the base.

39. A carrier head for positioning a substrate on a polishing surface, comprising:

a housing connectable to a drive shaft to rotate therewith;

a base; and

a gimbal mechanism that connects the housing to the base to permit the base to pivot with respect to the housing about an axis substantially parallel to the polishing surface, the gimbal mechanism including

a shaft having an upper end slidably disposed in a vertical passage in a vertical passage in the housing, and

a flexible member that connects a lower end of the shaft to the base, wherein the flexible member bends to permit the base to pivot with respect to the housing.

40. The carrier head of claim **39** wherein the flexible member comprises an annular ring with an inner circumferential portion connected to the shaft and an outer circumferential portion connected to the base.

41. The carrier head of claim **39** wherein the flexible member is bendable vertically but is rigid radially.

42. The carrier head of claim **39** further comprising a flexible membrane having a mounting surface for a substrate, the membrane connected to and extending beneath the base to define a boundary of a pressurizable chamber.

43. The carrier head of claim **39** further comprising a support structure, a flexure to connect the base to the support structure, and a flexible membrane connected to the support structure to define a boundary of a pressurizable chamber.

44. The carrier head of claim **39** wherein a stop is formed at the upper end of the shaft to engage a surface of the housing to prevent downward motion of the base.

45. The carrier head of claim **39** further comprising a loading mechanism connecting the housing to the base to apply a downward pressure to the base.

46. A carrier head for a chemical mechanical polishing apparatus, comprising:

a base;

a first flexible membrane having a mounting surface for a substrate, the membrane connected to and extending beneath the base to define a boundary of a first chamber; and

a second flexible membrane connected to the base and positioned above the first membrane to define a boundary of a second chamber, wherein a downward pressure on the first membrane exerted by the second membrane can be varied by forcing fluid into the second chamber.

47. The carrier head of claim **46** further comprising a support structure connected to the base by a flexure, wherein the first membrane extends beneath the support structure.

48. The carrier head of claim **47** wherein the second membrane is positioned to contact the support structure if a sufficient volume of fluid is forced into the second chamber.

49. The carrier head of claim **48**, wherein injection of fluid into the second chamber causes a bottom surface of the support structure to apply the downward pressure to a top surface of the first membrane.

50. The carrier head of claim **46** wherein the second membrane is positioned to directly contact the first membrane if a sufficient volume of fluid is forced into the second chamber.

51. The carrier head of claim **50** further comprising a support structure movably connected to the base, wherein the first membrane is attached to the support structure.

52. The carrier head of claim **51** wherein the support structure includes an aperture therethrough, and the second membrane is positioned to extend through the aperture to contact the first membrane.

53. The carrier head of claim **50**, wherein injection of fluid into the second chamber causes a bottom surface of the second membrane to apply the downward pressure to a top surface of the first membrane.

54. The carrier head of claim **46** used in a chemical mechanical polishing apparatus including a first fluid supply connected to the first chamber, a second fluid supply connected to the second chamber, and a sensor for measuring a pressure in the second chamber.

55. A carrier head for a chemical mechanical polishing apparatus, comprising:

a base;

a support structure movably connected to the base;

a first membrane portion connected to the base and defining a boundary of a first substantially circular chamber; and

a second membrane portion connected to the support structure wherein the second flexible membrane portion defines a boundary of a second substantially annular chamber which surrounds the first chamber.

56. The carrier head of claim **55** wherein a lower surface of the first membrane portion contacts an upper surface of the second membrane portion.

57. The carrier head of claim **56** wherein the lower surface of the first membrane portion is adhesively attached to the upper surface of the second membrane portion.

58. A carrier head for a chemical mechanical polishing apparatus, comprising:

a base;

a support structure including a support plate having a recessed region therein, the support structure connected to the base by a flexure; and

a flexible membrane having a mounting surface for a substrate, the membrane connected to and extending beneath the support structure to define a boundary of a chamber that includes a first volume between the base and the support plate and a second volume and the membrane, wherein the membrane is configured to be drawn into the recessed region if fluid is forced out of the chamber.

59. The carrier head of claim **58** wherein the support plate includes a passage connecting the first volume to the second volume.

60. A method of sensing the presence of a substrate in a carrier head, comprising the steps of:

pressurizing a first chamber formed by a first flexible membrane having a mounting surface for the substrate;

pressurizing a second chamber formed by a second flexible membrane to a first pressures;

forcing fluid out of the first chamber to create a reduced pressure region to chuck the substrate to the mounting surface; and

measuring a second pressure in the second chamber.

**61**. The method of claim **60** further comprising indicating that the substrate is present in the carrier head if the second pressure is greater than the first pressure.

**62**. The method of claim **60** further comprising indicating that the substrate is not present in the carrier head if the second pressure is equal to the first pressure.

**63**. The method of claim **60**, further comprising comparing the first and second pressures to determine if the substrate is chucked to the mounting surface.

**64**. The method of claim **60**, further comprising sealing the second chamber.

**65**. The method of claim **60**, further comprising placing a substrate against the mounting surface.

**66**. The method of claim **60**, wherein the second chamber is compressed by upward motion of the substrate if the substrate is present in the carrier head when the first chamber is evacuated.

**67**. A method of chucking a substrate to a mounting surface of a carrier head, comprising the steps of:

positioning a substrate against a mounting surface of a carrier head;

forcing fluid into a first chamber having a boundary defined by a first flexible membrane to apply a downward pressure to an annular area of substrate; and

forcing fluid out of a second chamber having a boundary defined by a second flexible membrane to draw the second membrane upwardly and create a reduced pressure region bounded by the annular area to chuck the substrate to the mounting surface.

**68**. The method of claim **67**, wherein the first membrane applies a downward force to an annular area of the second membrane.

**69**. The method of claim **68** wherein first membrane directly contacts the second membrane to apply the downward force.

**70**. The method of claim **68** wherein the first membrane contacts a support structure, and the support structure contacts the first membrane to apply the downward force.

**71**. The method of claim **67** wherein the first flexible membrane directly contacts the substrate to apply the downward force.

**72**. The method of claim **71** wherein the first chamber is substantially annular.

**73**. A carrier head for a chemical mechanical polishing apparatus, comprising:

a base;

a first flexible membrane portion connected to and extending beneath the base to form a first chamber; and

a second flexible membrane portion connected to and extending beneath the base to form a second substantially annular chamber which surrounds the first chamber, wherein the first and second membrane portions provide a substrate receiving surface.

**74**. The carrier head of claim **73** wherein a lower surface of the first membrane portion contacts an upper surface of the second membrane portion.

**75**. The carrier head of claim **74** wherein the lower surface of the first membrane portion is adhesively attached to the upper surface of the second membrane portion.

**76**. A carrier head for a chemical mechanical polishing apparatus, comprising:

a base; and

a flexible member connected to the base to form a first chamber and a second chamber, a lower surface of the flexible member providing a substrate receiving surface with a inner portion connected to the first chamber and a substantially annular outer portion surrounding the inner portion and connected to the second chamber.

**77**. A carrier head for a chemical mechanical polishing apparatus, comprising:

a base;

a support structure connected to the base by a flexure so as to be moveable independently of the base; and

a flexible membrane having a mounting surface for a substrate, the membrane connected to and extending beneath the support structure to define a boundary of a pressurizable chamber, wherein a portion of the membrane along an edge of the mounting surface is vertically movable relative to the base.

**78**. The carrier head of claim **77**, wherein the support structure includes a generally cylindrical outer rim, and the flexible membrane extends around a rim of the support structure.

**79**. A carrier head for a chemical mechanical polishing apparatus, comprising:

a base;

a retaining ring secured to the base;

a support structure connected to the base by a first flexible member so as to be moveable independently of the base; and

a second flexible member having a mounting surface for a substrate, the second flexible member connected to and extending beneath the support structure to form a boundary of a pressurizable chamber, wherein the support structure and first flexible member are configured so that at least a portion of a downward force on the first flexible member caused by injection of fluid into the chamber is transferred to the retaining ring.

**80**. The carrier head of claim **79**, wherein an inner portion of the first flexible member extends over an outer portion of the mounting surface of the second flexible membrane.

**81**. The carrier head of claim **80**, wherein a gap separates the outer portion of the support structure from the inner portion of the first flexible member.

**82**. The carrier head of claim **81**, wherein the first flexible member can extend downwardly into the gap without contacting the support structure.

**83**. An apparatus for a chemical mechanical polishing system, comprising:

a carrier head having a base and a flexible membrane coupled to the base to define a boundary of a first chamber, a lower surface of the flexible membrane providing a substrate receiving surface;

a vacuum source connected to the chamber to evacuate fluid from the chamber;

a pressure sensor to generate an output signal, wherein the carrier head is configured such that if the substrate is attached to the substrate receiving surface and the chamber is evacuated, the sensor measures a first pressure that is different from a second pressure that would result if the substrate were not attached to the substrate receiving surface; and

a processor configured to indicate whether the substrate is attached to the substrate receiving surface in response to the output signal.

**84**. The apparatus of claim **83**, wherein the carrier head includes a second chamber, and the pressure sensor is placed to measure the first and second pressures in the second chamber.

**85**. The apparatus of claim **84**, wherein the second chamber is located above the first chamber so that inward motion of the flexible membrane compresses the second chamber.

**86**. A method of sensing the presence of a substrate in a carrier head, comprising the steps of:

pressurizing a first chamber formed by a first flexible membrane having a mounting surface for the substrate;

forcing fluid out of the first chamber to create a reduced pressure region to chuck the substrate to the mounting surface; and

measuring a pressure associated with the carrier head to determine whether the substrate was successfully chucked to the mounting surface.

**87**. A method of chucking a substrate to a mounting surface of a carrier head, comprising the steps of:

positioning a substrate against a mounting surface of a carrier head that is provided by a lower surface of a first flexible membrane that defines a boundary of a first chamber;

forcing fluid into a second chamber to apply a downward pressure to an upper surface of the first membrane in a first region; and

forcing fluid out of the first chamber to create a second region of reduced pressure that is bounded by the first region to chuck the substrate to the mounting surface.

**88**. The method of claim **87**, wherein forcing fluid into the second chamber causes a second flexible membrane to extend downwardly to directly contact the upper surface of the first membrane.

**89**. The method of claim **87**, wherein forcing fluid into the second chamber causes a second flexible membrane to extend downwardly and apply a downwardly pressure to a support structure that contacts the upper surface of the first membrane.

**90**. A carrier head for chemical mechanical polishing, comprising:

a base;

a flexible membrane coupled to and extending below the base to form a first chamber having a first pressure, a lower surface of the flexible membrane providing a mounting surface for the substrate, wherein a first load applied to the substrate is controlled by the first pressure;

a retaining ring coupled to the base; and

a second chamber having a second pressure, the chamber located above the base to control a downward load on the base so that a second load applied to the retaining ring is increased by increasing the second pressure and decreased by increasing the first pressure.

**91**. A method of chemical mechanical polishing s substrate, comprising:

holding a substrate with a carrier head having a substrate mounting surface and a retaining ring;

selecting a first pressure for a first chamber in the carrier head, the load applied to the substrate being controlled by the first pressure; and

selecting a second pressure for a second chamber in the carrier head, the load applied to the retaining ring being increased by increasing the second pressure and decreased by increasing the first pressure.

**92**. A carrier head for a chemical mechanical polishing apparatus, comprising:

a housing connectable to a drive shaft to rotate therewith;

a base located below the housing;

a loading mechanism that connects the housing to the base to permit vertical movement of the base relative to the housing; and

a cushion attached to a lower surface of the housing to limit upward movement of the base.

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# UNITED STATES PATENT AND TRADEMARK OFFICE
# CERTIFICATE OF CORRECTION

PATENT NO. : 6,183,354 B1
DATED : February 6, 2001
INVENTOR(S) : Manoocher Birang et al.



It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Title page,
Item [56], **References Cited**, U.S. PATENT DOCUMENTS, add
-- 5,733,182 A * 3/1998 Muramatsu et al. .................... 451/289 --

Signed and Sealed this

Third Day of May, 2005

JON W. DUDAS
*Director of the United States Patent and Trademark Office*